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Flooring systems from locally grown Casuarina wood: Performance evaluation based on simulated in-service testing

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Flooring Systems from Locally Grown Casuarina Wood: Performance evaluation based on simulated in-service testing

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By

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ABSTRACT

In Egypt there is a lack of forestry regions and it depends totally on imported wood from several areas as Europe and Australia. *Casuarina Glauca Sieber ex Spreng* is an evergreen tree with very hard, heavy and a dark-brown structured wood that is grown extensively in Egypt with very little water consumption (often irrigated using waste water), fast growth rate and a relatively low cost. Almost all of the wide range of wood flooring products are imported including hardwood floors, engineered flooring systems and medium density fiber boards.

The main objective of this research is to develop a wood flooring system from locally grown wood (Casuarina Glauca) to be used as an alternative to the imported woods used for flooring systems in the Egyptian market by identifying the various types and classifications of wood flooring systems in Egypt and world-wide. The next step is to determine the relevant standard test methods and procedures and manufacture the required equipment and apparatus according to standards. Then perform the determined tests to a representative sample of the most commonly used hardwood floorings in Egypt to be compared with the proposed Casuarina Glauca flooring system. Finally, identify different finishing techniques and products used in the Egyptian market and studying their effects on performance.

The Casuarina Glauca and Oak samples showed no significant statistical difference in the concentrated loading test, falling ball indentation and floor surface indentation from small area loads. This indicates that they have similar resistance to heavy loads, small area loads and impact loads. While the performance of Casuarina Glauca was better in the Janka hardness, rolling load, coefficient of friction and abrasion which indicates higher hardness, resistance to rolling loads and abrasion resistance.

The types of coatings compared namely, polyurethane and acrylic polyurethane were not found to contribute significantly to tests such as concentrated loading, falling ball indentation, Janka hardness, rolling load, small area loads indentation however, the effect was observed in the surface wetting, coefficient of friction, abrasion resistance test and the resistance to staining. Samples coated with polyurethane, normal and acrylic, had less doming when exposed to moisture, a higher resistance to abrasion, a smaller coefficient of friction and better resistance to stains and cigarette burns with the acrylic polyurethane providing a slightly better performance.

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Thank you.

CHAPTER 1:

INTRODUCTION

In Egypt there is a lack of forestry regions, therefore wood is considered an expensive commodity in the construction world. Egypt depends totally on imported wood from several areas as Europe and Australia and that's why it is so expensive to be used as structure material in construction industry. *Casuarina Glauca Sieber ex Spreng* is an evergreen tree that is grown extensively in Egypt with very little water consumption (often irrigated using waste water), fast growth rate and a relatively low cost. The Casuarina wood is very hard, heavy, with a dark red-brown structure; hence the name ironwood is derived from its properties. The Casuarina trees are considered relatively new to Egypt, which were introduced from South East Asia (Australia) at the beginning of the 19th century. Casuarina is naturally used as wind shelterbelts along highways and farms, preventing dust and wind from disturbing anything. It is also considered as a great source of firewood, even when it's green it may be combusted. Information on this type of wood in Egypt is limited in terms of its mechanical and physical properties for several reasons. Furthermore, the properties of Egyptian woods have received very little attention in the previous literature and research efforts.

Simultaneously, there is a huge demand for wood products in Egypt for furniture, construction, doors and windows as well as flooring. Flooring specifically is always in high demand and a wide variety of products are currently available in the market. It is estimated that the price of the Casuarina Glauca wood is approximately one fourth the price of commercial Oak where the price of a cubic meter of Oak is around 12,000 LE while the cubic meter of Casuarina Glauca is approximately 3,000 LE. This dictates a very attractive opportunity for the Casuarina Glauca wood if the performance is similar to the Oak products.

The genus Casuarina comprises nearly 50 species (although different sources may claim different number of Casuarina species – see for example Wikipedia). The genus is native to Australia, the Indian subcontinent, southeast Asia, and islands of the western Pacific Ocean and are found in the Southern Hemisphere from India and Malaya to the islands of the South Pacific Ocean. The Casuarina is a genus in the family Casuarinaceae, following the taxonomy:

Kingdom	Plantae
Clade	Angiosperms
Clade	Eudicots
Clade	Rosids
Order	Fagales
Family	Casuarinaceae

Note that Casuarina are angiosperms and hence considered hardwood. The species found its greatest development in Australia (where they occur both in the arid areas of the center and the higher rainfall coastal regions and in Florida, USA. The trees vary in size from small to large and can grow to be up to 35 meters tall. They are evergreen shrubs and trees. The fruit is a woody, oval structure superficially resembling a conifer cone, made up of numerous carpels, each containing a single seed with a small wing. The generic name is derived from the Malay word for the cassowary, kasuari, alluding to the similarities between the bird's feathers and the plant's foliage, and their principal value is for shelter, soil conservation and rehabilitation, timber or fuel supply.

A few species were introduced into Egypt in the 19th century where they are planted essentially as windbreaks and to supply wood for local industry. The trees proved to be superior to several other exotic and native species as they are well adapted to local severe climatic and soil conditions. Plenty of them have been used as windbreaks in the north western regions of Egypt where desert reclamation is underway.

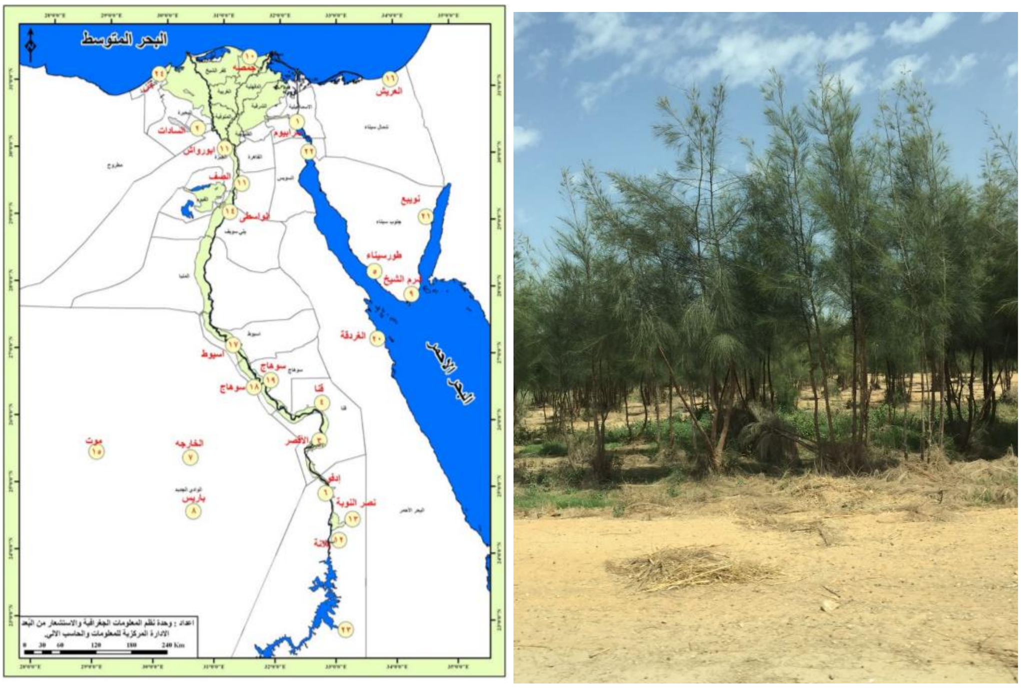


Figure 1 - Location of some 15 sites with Casuarina trees grown on treated sewage.

A Casuarina breeding program for shelterbelt plantations was initiated at Alexandria University, the first step of which has been to identify the species. (O.a, M.h, M.l, & Gazia, 1976) examined in detail the morphological and taxonomical characteristics of Casuarina species grown in Egypt and were able to identify three distinct species; namely C. Equisetifolia Forst.. C. Cuminghamiana Miq. and C. glauca Sieber et Spreng. A natural hybrid between the last two species was also recognized and described morphologically by them for the first time. The identification of the above-noted species and the hybrid was confirmed after a serological study by (O.a et al., 1976) and a quantitative determination of flavonoids and phenolics by (Saleh & El-Lakany, 1979). Moseley (1948) described the wood anatomical features of many Casuarina species in detail.

Although Egypt is not known for its forests, there are several kinds of Wood grown in Egypt and they vary in nature and type. The ministry of environment has a list of the forests containing Casuarina wood grown in Egypt along with several other species. A map showing these forests which almost exclusively grown on treated sewage water can be found in figure 1.

Another very valuable resource on forests and tree species grown in Egypt was found to be the publication by the Forestry Department Food and Agriculture Organization (FAO) of the

United Nations. The FAO published a global forest resources assessment country reports every five years and a report was published for Egypt in 2005, 2010 and 2015. FAO, at the request of its member countries, regularly monitors the world's forests and their management and uses through the Forest Resources Assessment Programme. In the report definitions for Forests, Other Wooded Land, Other Land, Other Land with Tree Cover and Inland Water Bodies are provided. For example, a forest is defined as: "*Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use*." Some natural tree formations can be found either in the form of scattered trees with a crown density of less than 10 percent in Gebel Elba (an estimated 19600 ha) or as mangroves along the Red Sea coast (an estimated 390 ha).

Table 1 shows the number of standing trees over the years and it is clear that Casuarinas spp. in general (including all three species and any hybrids) are in the order of forty million trees divided among trees belonging to the government and trees belonging to individuals. The area of plantations was calculated based on 3x3 m for the Casuarina and it also clear from the table that Eucalyptus spp. comes a close second in terms of the number of trees grown. All plantations are classified as forests according to the updated FRA 2010 Categories and definitions, while mangroves and the natural woody vegetation in Gabal Elba and the plain of the Sinai Peninsula are classified as other wooded land (OWL). The report also showed that 8,327 fedans in total around Egypt are considered forests or other wooded lands.

Table 1 - number of standing trees in 1993, 2004 and 2009

Species	**Trees belong to government (1000trees)**			**Trees belong to individuals (1000 trees)**		
	1993	**2004**	**2009**	**1993**	**2004**	**2009**
Casuarinas spp	14788	19400	20176	16788	22390	23285.6
Eucalyptus spp	1970	2708	2816	1883	2604	2708
Dalbergia sissoo	2485	3401	3537	624	854.44	888.6
Salix & Populus	151	207	215	1700	1655.88	1721
Morus spp	112	153	159	630	865.11	899.6
Acacia spp	517	708	736	710	972.52	1011
Cypressus spp	215	314	327	52	68.88	71
Albizzia lebbek	18	18	18	20.5	25.42	27.2
Khaya senegalensis	10	774	656	0.5	0.82	1.2
Other Species	1984	2715	2911	1184	1495.68	1555
Total	**22250**	**30398**	**31551**	**23592**	**30932.75**	**32168.2**

- *Most of the growing stock in Egypt is linear plantations which are mostly less than 20 rows in width.*
- *Only few areas are in the form of wood lots irrigated with treated sewage water.*

Figure 2 - The two most common species of Casuarina found in Upper Egypt, C. Cuminghamiana Miq. (right hand side) and C. glauca Sieber et Spreng. (Left hand side).

1.1 Problem Statement

Egypt imports almost all of the wooden flooring material used today. It is estimated that Egypt's need for wooden floors, in the residential market alone, are in excess of 100,000 square meters annually with a conservative estimate of the current market annual value of 40 million EGP. This quantity is all imported.

Almost all of the wide range of wood flooring products are imported including hardwood floors, engineered flooring systems and medium density fiber boards (known as MDF in the market). This puts a strain on the foreign currency demands needed to acquire these material, since the huge portion of this value is imported. If only a small portion of the current demand for wooden floors can be replaced with a locally developed material, a significant dent can be placed on the amount of foreign currency needed to import wood in Egypt.

1.2 Objectives of this research

The main objective of this research is to develop a wood flooring system from locally grown wood (Casuarina Glauca) to be used as an alternative to the imported woods used for flooring systems in the Egyptian market.

Precisely, the main objective can be divided into the following:

1. Identify various types and classifications of wood flooring systems in Egypt and world-wide.
2. Determine the relevant standard test methods and procedures and manufacture the required equipment and apparatus according to standards.
3. Perform the determined tests to a representative sample of the most commonly used hardwood floorings in Egypt to be compared with the proposed Casuarina Glauca flooring system.
4. Identify different finishing techniques and products used in the Egyptian market and studying the effect on performance of Casuarina Glauca flooring system.

1.3 Organization of this research

This thesis document is divided into 6 chapters as described next.

Chapter 1: Introduction - provides an introduction to the thesis topic and gives a brief background of the locally grown wood (Casuarina Glauca) proposed for use in the wooden flooring system. The objectives of the research and adopted methodology are presented thereafter in this chapter.

Chapter 2: Literature Review - illustrates the research work that has been addressed to wooden flooring in academic references tackling several aspects in the design of wooden flooring systems such as the types of coatings to the wooden specimens, visual and tactile preferences of consumers for wooden floors.

Chapter 3: Development of Wood Flooring System - entails how the proposed Casuarina Glauca wooden flooring system has been developed. Firstly, the classification of wooden flooring in the Egyptian market and international standards are identified. Then the test methods stipulated in the international standards are outlined. Finally, the lamparquet design of the Casuarina Glauca flooring system is illustrated in conjunction with the common practice and compliance with standards.

Chapter 4: Methods and Materials - describes the methods and materials adopted in order to satisfy the testing requirements of this research. The experimental design is initially outlined consisting of the types of wood to be tested and finishing products used for the samples. Then the samples and apparatus prepared for each test are explained including the number of samples tested, the manufactured apparatus and the testing procedure.

Chapter 5: Results and Discussion - discusses the results obtained from each test in the form of graphs, tables and photographic images. Followed by analysis and comparison of the test outcomes of the different types of wood and different coatings used for the samples.

Chapter 6: Conclusion and Recommendations – presents the main findings of this research and ends the thesis giving recommendations for future research work relative to the topic.

CHAPTER 2:

LITERATURE REVIEW

This chapter illustrates the research work that has been addressed to wooden flooring in academic references tackling several aspects in the design of wooden flooring systems such as the types of coatings to the wooden specimens, visual and tactile preferences of consumers for wooden floors. The chapter categorizes the research carried out into four distinct categories; performance of wood flooring systems, substrate design for engineered wood, structural analysis of wood flooring and Bamboo flooring systems.

2.1 Performance of wood flooring systems

Along with the emergence and growing popularity of multi-layered engineered wood since the 1970's, research has been directed to evaluating the performance of the composite wooden floors due to the hygrometric properties of different types of wood. Blanchet et. al studied the performance of five different constructions of engineered wood in terms of dimensional stability. Results showed that the construction with a 4-mm sugar maple surface layer, 8-mm white birch core layer and 2-mm yellow birch veneer backing layer was the best construction showing the least cupping distortion. The study also examined the effect of the use of varnish as a finishing system which reduced the cupping distortion by 50% therefore illustrating the importance of the quality of finishing used for the multi-layered engineered wooden flooring system. (Blanchet, et. al, 2003)

Blanchet also studied the performance of various components of engineered wood flooring when subjected to aging cycles in terms of temperature and humidity. Variations in the engineered wood flooring components included three different substrates (Russian plywood, HDF and Oriented Strand Board), three surface components (sawn, sliced and peeled) and four adhesives (PolyVinyl Acetate (PVA) type I, epoxy, polyurethane and Emulsion Polymer Isocyanate (EPI)). Results showed that the substrates had the highest impact on the aging of the flooring with the Russian plywood performing best, the Sawn surface components had the poorest performance in terms of aging in comparison with the other surface components and the adhesives had similar performances except for epoxy which was the worst adhesive in terms of aging. (Blanchet, 2008)

In a research done by Nordvik et. al, Kansei engineering was performed on a sample of 200 people in order to develop a link between varying physical properties of floors and the perceptions of customers. This was done by forming statistical connections between customer impressions such as vivid, realistic, good looking, colourful, harmonious and modern to eight different types of wood through digital images. The results showed that wooden floors with calm, yellow, dark and three-stripped pattern were perceived as good-looking floors and the Oak Haro was the closest fit to these traits. (Nordvik, et. al, 2009)

Berger et. al performed a study to determine the tactile preferences of male and female Austrian consumers towards wooden floors in terms of temperature, smoothness and hardness. Since recent developments of wooden floors such as laminate floors have mimicked the visual appearance of wooden floors, the research aimed to distinguish different types of floors in order to identify the consumers' preferences and direct the product positioning and sales tactics accordingly. Results of the tests done by the hand and feet showed consumer preferences towards oiled flooring surfaces over laminate and multi-layered lacquer parquet surfaces as the oiled surfaces were perceived as warm, rough and fairly soft as opposed to the laminate flooring which was perceived as cold, smooth and hard. (Berger, et. al, 2006)

In a research done by Delgado et. al, an expert system was developed to aid users in the inspection and maintenance of their wooden flooring systems. The expert system includes correlation matrices between the classification of the defects, their probable causes and their proposed repair techniques. The inspection system had been validated over various types of wooden floor coverings such as hardwood, softwood, laminate floors and engineered wood floors. The system was also validated through multipurpose buildings including residential buildings, historical buildings, educational buildings, restaurants, hospitals and outdoor areas. The classification of the defects include joint defects and surface defects further divided into aesthetic and functional defects. While the classification of the causes include production errors, design errors, execution errors, exterior mechanical actions, biological actions, environmental actions and maintenance errors. Since wooden floors can be refurbished and reused, it is important to accurately identify the defects and choose the suitable repair mechanism to avoid unnecessary replacement or additional repair costs. et. al, 2013)

Calatan et. al developed a comparative study on the physico-mechanical characteristics and performance of five flooring types based on standardized tests. The types of floors included Solid Oak, Baking Oak, Stratified Oak, Solid Walnut and Stratified Walnut and they were tested for linearly distributed and concentrated loads, thermal insulation characteristics and slip resistance. Variations in the tested samples included different wood types, technological processing such as stratification, different thicknesses and different varnish coatings. Results of the tests showed that the wood type, material processing, thickness and varnish had a direct influence on the behaviour of the wooden floors under distributed and concentrated loads. As for thermal insulation, stratified Oak was found to have the best thermal insulation when compared to the other types. The slip resistance of the wood flooring is largely impacted by the type of finish to be used therefore, the coating used shall be chosen according to the traffic intensity, location and environmental conditions. (Călătan, et. al, 2014)

2.2 Engineered Wood Flooring

In another research, Bouffard et. al, the substrate used for the engineered wood flooring was studied. An Oriented Strand Board (OSB) was proposed to replace the commonly used Baltic birch plywood. The OSB was made by compressing layers of wood flakes using different types of adhesives such as liquid phenol formaldehyde resin, polydiphenylmethane diisocyanate (pMDI) resin and mixtures of both. Three samples with different OSB prototypes were tested and compared with commercial OSB and commercial plywood in terms of cupping deformation and edge delamination. Results showed that the long term performance of the engineered wood floors made with the proposed OSB did not vary significantly when compared to the similar engineered wood floors made with Baltic birch plywood. (Bouffard, et. al, 2010)

Since Engineered Wood Flooring involves combining various types of materials, numerous combinations and innovations are readily introduced into the research. Bouffard & Blanchet considered using medium and high-density fibreboards (MDF and HDF) as substrates for Engineered Wood Flooring. Also, two types of face layers were compared in terms of cupping distortion and it was concluded that the sliced face layer had better performance that the sawn face layer with lower cupping distortion. Furthermore, the use of melamine-impregnated paper as backing layer to the flower resulted in significant reduction in the cupping distortion of the engineered wood flooring samples. (Bouffard & Blanchet, 2009)

2.3 Finite element method design

In another research by Blanchet et. al, the finite element method is proposed to design engineered wood flooring layers and validated using experimental and numerical approaches. The purpose of this research was to determine the parameters with the most impact on the cupping deformation of different constructions of engineered wood flooring. Results showed that the mechanical properties and thickness of the core layer are the most dominating factors that affect the cupping distortion of engineered wood floors while the backing layer has a smaller impact. This design approach provides room for major cost savings and better quality of engineered wood flooring systems. (Blanchet, Cloutier, Gendron, & Beauregard, 2006)

2.4 Bamboo Flooring

Barbosa et. al performed physical-mechanical analysis on bamboo laminates and Pine wood Edge-Glued Panels (EGP) to determine the applicability of the composite for internal floors. The simulation testing was composed of indentation due to small area loads, falling ball impact, rolling load, abrasion and determination of coefficient of friction tests and the results indicated that the bamboo composite is viable and feasible in comparison with other types of wooden flooring and therefore it can be used for internal flooring. (Barbosa et al., 2014)

CHAPTER 3:

DEVELOPMENT OF WOOD FLOORING SYSTEM

This chapter describes how the proposed Casuarina Glauca wooden flooring system has been developed. Firstly, the classification of wooden flooring in the Egyptian market and international standards are identified. Then the test methods stipulated in the international standards are outlined. Finally, the lamparquet design of the Casuarina Glauca flooring system is illustrated in conjunction with the common practice and compliance with standards are presented.

3.1 Classification

3.1.1 Egyptian Classification

Hardwood parquet flooring is one of the most popular flooring types used in Egypt due to its aesthetics and prestigious look. It has been used widely and has been in the market for a very long time however, all hardwood floors used in Egypt are made from imported wood which makes it an expensive item. Hardwood floors in Egypt are classified according to the source of wood (type and/or country of origin) and the method of fixing.

The various types of hardwood flooring imported in Egypt include: Pine; Beach Pine; Oak; Mahogany and Iroko. These woods are imported from different parts across the globe and vary in colour, size and mechanical properties and hence have ranging prices. Types like the Pine are imported from northern European countries such as Poland, Sweden, Finland and Yugoslavia therefore have light colours and their prices range from 200-400 Egyptian Pounds per m^2. While the Beach Pine, Oak and Iroko are imported from the Americas and have a darker reddish look with prices ranging from 300-1200 Egyptian Pounds per m^2. The Mahogany woods are imported from Africa and have the darkest colours and are grown in tropical regions, their prices range from 400-600 Egyptian Pounds per m^2.

Hardwood parquet flooring can be assembled in two ways, the first is the tongue and groove method as shown in Figure 3 below which enhances the interlock of the wooden strips and facilitates the nailing process. This assembly is usually associated with an underlay made of wood to provide means for fixing the wooden strips and allow for Finished Floor Level adjustment with the adjacent zones in the layout. The other method is the glue-down method, also referred to as lamparquet in the European Norms, where the wooden strips are glued side by side and laid on top of a concrete or ceramic subfloor. The thicknesses of the wooden flooring strips are usually either 12 mm or 22 mm as a common practice due to the specifications of the sawing machine.

Figure 3 Tongue and groove wood assembly

As for the finishing of the wooden surfaces, the process involves applying a sealant layer to the installed wood strips in order to seal the porous wooden floor and minimize surface moisture absorption followed by one or two layers of varnish, which may contain a colouring agent, to provide protection, smoothness and a glossy look to the wooden floor. The most common varnish used for wooden flooring is the polyurethane composites available at a variety of different vendors with prices ranging from 25-55 Egyptian Pounds per m^2 of finished flooring. Polyester based varnishes are also an option for wooden surfaces however it is not commonly used for wooden flooring since it is not durable. Another type of coating used for the finishing of hardwood floors is the marine epoxy coating however, it is not commonly used due to its high price relative to the polyurethane finishing.

3.1.2 American Standards for wooden floors

The American Society for Testing and Materials (ASTM) have developed a variety of standard test methods for different wooden products. Specifically, ASTM D2394-17 is a standard test method for *Simulated Service Testing of Wood and Wood-Base Finish Flooring*. These standard test methods apply to all types of wooden floors.

3.1.3 European Standards for wooden floors

The European Norms (standards) for wood flooring is classified according to the wood flooring type as defined. Wood flooring is defined as an assembly of wood elements in the form of preassembled boards or parquet panels constituting a wearing surface of a floor. Wood floorings are manufactured in a factory and may be prefinished in the factory and finished on site after sanding. (EN13756) Wood floorings are classified in the European Norms into the following:

- Cork Flooring
- Laminate Flooring (EN13329)
- Wooden Floor Covering

  - Solid parquet elements with tongues and grooves (EN 13226);

  - Solid lamparquet products (EN 13227);

  - Solid wood overlay elements including blocks with an interlocking system (EN 13228);

  - Mosaic parquet elements (EN 13488);

  - Multi-layer parquet elements (EN 13489);

  - Solid pre-assembled hardwood board (EN 13629);

  - Solid softwood floor boards (EN 13990);

  - Parquet: vertical finger, wide finger and module brick (EN 14761).

- Bamboo Floor covering

3.2 Testing of Wood Flooring

The tests included in the ASTM D2394-17 for Wood and Wood-base finish flooring include a set of tests to simulate the service loading and conditions that the flooring may be subjected to. The tests include Loading tests such as Concentrated loading, Floor surface indentation from small area loads, Falling ball indentation and Rolling load tests. The Mechanical tests include the Abrasion resistance and Coefficient of friction tests in addition to the Moisture tests which include the Surface wetting test.

The European Norms contain an extensive set of documents for various classifications of wooden flooring systems. EN14342 Wood Flooring – Characteristics, Evaluation of Conformity and Marking is applicable to wood flooring products and parquets and evaluates a set of performance characteristics such as reaction to fire, formaldehyde content, pentachlorophenol emission, tensile strength, slip resistance, thermal conductivity and biological sustainability. Specifically, EN13227 pertinent to lamparquet flooring contains a set of nominal dimensions, finishing requirements, moisture content and installation procedures. While EN13329, EN438 & EN424, EN425 pertinent to laminate flooring include a set of simulated service tests such as Abrasion resistance, Impact resistance, Effect of furniture leg, Effect of castor chair, Thickness swelling, Resistance to cigarette burns & Resistance to staining.

Figure 4 below shows the table of contents of the EN 13227 standard for lamparquet products. The tests in the European Norms have simialr performance goals to the ASTM D2394-17 *Simulated Service Testing of Wood and Wood-Base Finish Flooring* therefore, the tests in the ASTM D2394-17 were followed in addition to two tests from the European Norm EN438 namely, Resistance to cigarette burns and Resistance to staining.

EN 13227:2002 (E)

Contents

Figure 4 - Table of contents for the Lamparquet standard EN 13227 showing the various items covered by the standard. Item 5.6.1 discusses the technical characteristics when in service.

3.3 Lamparquet Design

The samples manufactured for the flooring system proposed were designed taking into consideration the definition of lamparquet wooden floors in the European Norms EN13227, the common practice used for wooden flooring elements in Egypt and the dimensions of the timber logs that will be quarter sawn into the designed dimensions. The European Norms define lamparquet elements having a thickness of 9-11 mm, a length of 120-400 mm and a width of 30-75 mm. Hence the Casuarina Glauca samples were designed to have a length of 300 mm and a width of 45 mm. However, due to the sawing machine specifications, a thickness of 12.5 mm (1/2") was used in the manufacture of the specimens, as shown in Table 2. The dimension of 45 mm by 300 mm was found to have a minimal waste of quarter sawn wood. The different sawing methods of raw timber are illustrated in Figure 5 below. Therefore, the samples of the Casuarina Glauca Lamparquet were 45 mm wide, 12.5 mm thick and 300 mm long as shown in Figure 6. The samples consisted of 4-5 strips glued together on a plastic mesh as it would be used in real life situation to ease the installation process. The moisture content of the samples was ensured to be below 10% before the wood was assembled and finished in order to secure dimensional stability and accurately determine the physical performance of the wood. A drying kiln with temperatures around 70 Celsius degrees was used in this process which took around 3-4 weeks.

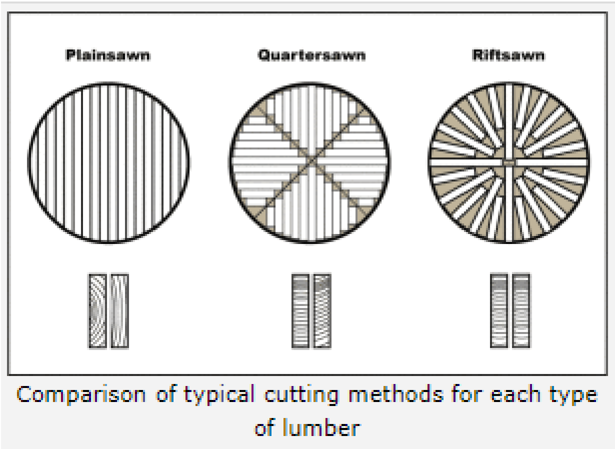


Figure 5 - Difference between plainsawn, quarter sawn & riftsawn timber

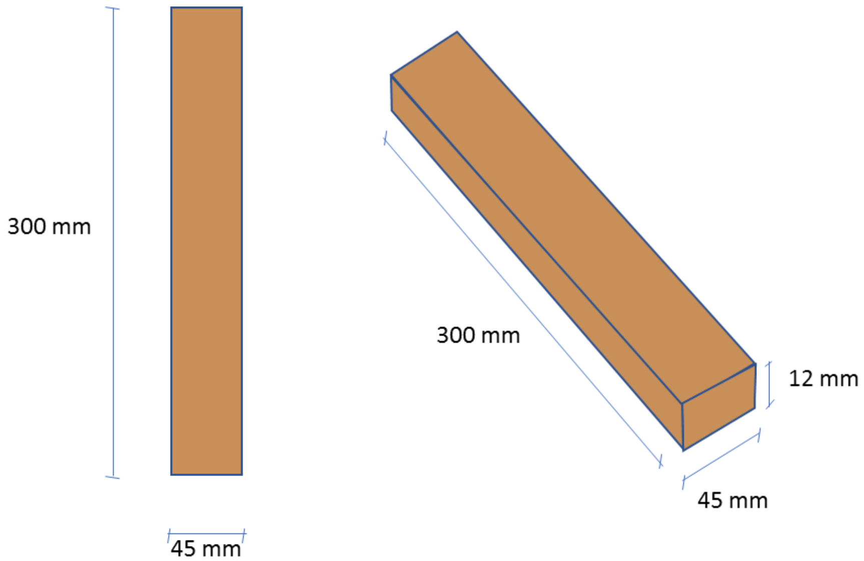


Figure 6 - Lamparquet sample size

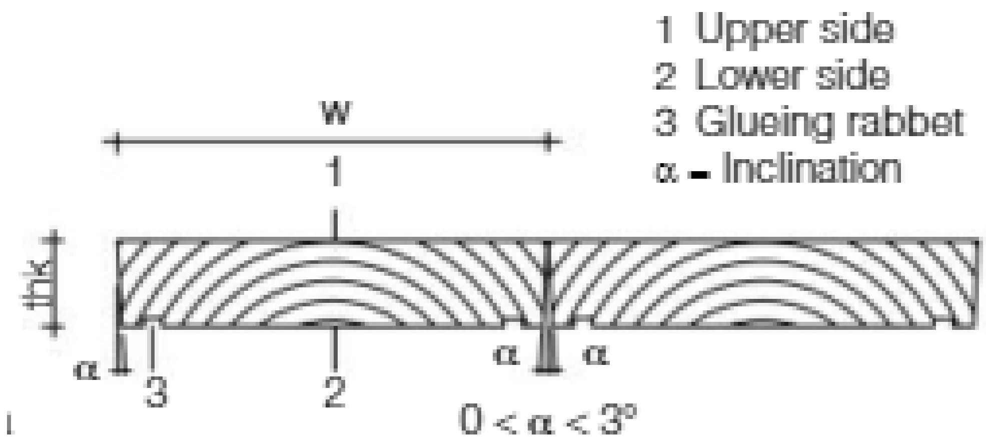


Figure 7 - EN13227 dimensional requirements for lamparquet products

Table 2 - Lamparquet design nominal dimensions as per EN13227 in addition to proposed design

Product	**Thickness (mm)**	**Length (mm)**	**Width (mm)**
Lamparquet element	9-11	120-400	30-75
Large lamparquet elements incl. parquet board	6-10	>400	60-180
Maxi lamparquet element	13-14	350-600	60-80
Casuarina Glauca proposed design	12.5	300	45

CHAPTER 4:

METHODS AND MATERIALS

This chapter describes the methods and materials adopted in order to satisfy the testing requirements of this research. The experimental design is initially outlined consisting of the types of wood to be tested and finishing products used for the samples. Then the samples and apparatus prepared for each test are explained including the number of samples tested, the manufactured apparatus and the testing procedure.

4.1 Experimental Design

4.1.1 Type of wood

In order to compare the Casuarina Glauca wooden flooring system proposed, two control types of wood have been selected from the market and manufactured with the same dimensions. Oak was selected as a high quality product and Pine was selected to represent a lower quality product of the commonly used products in the market.

4.1.2 Finish Type

The coating used on wooden floors contributes to various characteristics and performance measures such as slipperiness and abrasion resistance. Two-component polyurethane coatings are the most commonly used coatings used for wooden floors due to their properties such as abrasion and scratch resistance, excellent adhesion, resistance to staining and gloss appearance. Therefore, all the tests performed included samples without coating and samples with a polyurethane finish. In addition to this, the Casuarina Glauca samples were coated with acrylic polyurethane finish which is known for better performance and resistance to moisture.

4.1.3 Testing

A set of nine tests were performed according to the referenced ASTM D2394-17 in addition to two tests from the European Norms including:

1. Loading Tests
    a. Concentrated Loading
    b. Floor Surface Indentation from Small Area Loads
    c. Falling Ball Indentation
    d. Rolling Load
2. Mechanical Tests
    a. Abrasion Resistance
    b. Coefficient of Friction
3. Moisture Tests
    a. Surface Wetting
4. Other Tests (from EN 438)
    a. Resistance to Staining
    b. Cigarette burns

4.2 Samples and Apparatus

4.2.1 Concentrated Loading

The concentrated loading test aims to study the resistance of the different wooden floors when subjected to heavy concentrated loads such as furniture or cabinets. The concentrated load is applied at two points on the specimen, namely point 1 simulating the loading condition near an end joint of the flooring and point 2 simulating the loading at the center of the specimen with even load distribution.

To perform the test, the 810 Material Test System (MTS) machine was used to apply axial load at the specified uniform rate of movement (2.5 mm/min) and measure the resultant axial displacement. Furthermore, a steel disk loading tool was fabricated as per ASTM D2394-17 with a diameter of 25 mm and rounded edges as shown in Figure 8.

Figure 8 a) 810 Material Test System machine used for loading and measuring indentation. b) Steel disk loading tool fabricated as per ASTM D2394-17

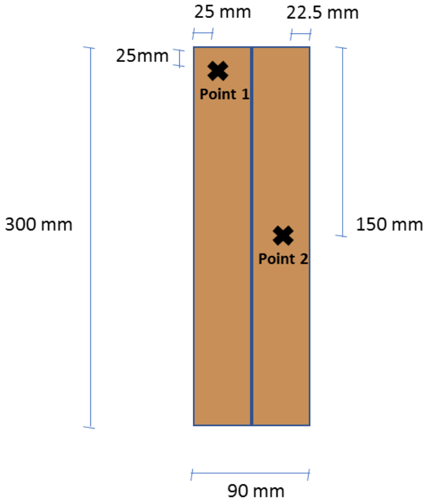


Figure 9 - Sample size of the Concentrated loading test

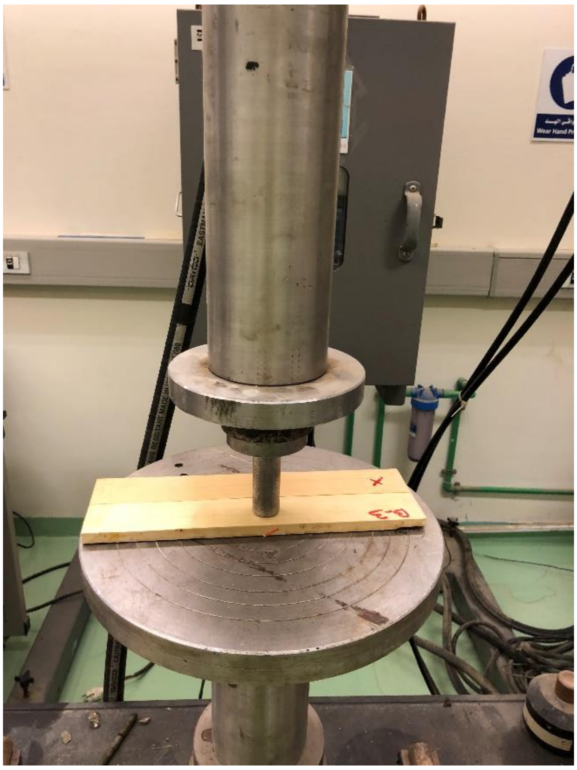


Figure 10 - Concentrated loading test assembly, a) test at point 1 top left corner and b) test at point 2 center of the specimen

4.2.2 Falling ball indentation

The falling ball indentation test aims to measure the resistance of the wooden flooring samples to impact resulting from dropped objects. The procedure stipulated in ASTM D2394-17 was followed where a steel ball with a weight of 535g was fabricated and a metal L-shaped plate was fabricated with openings for height adjustment and a hole equal to the diameter of the steel ball was made in order to avoid horizontal motion being applied to the dropped ball as shown in Figure 11.

The tested samples included Oak, Pine & Casuarina Glauca samples composed of 3 strips to form one tile. All the samples were tested without coating and with a polyurethane finish, while the Casuarina Glauca samples were also tested with an acrylic polyurethane finish. Four samples per wood type per finish were tested. The different heights of the dropped ball were marked on the samples to be 50 mm apart and a plumb bob was used to position the sample exactly below the ball.

Figure 11 - Falling ball test setup providing means for height adjustment and avoiding horizontal motion

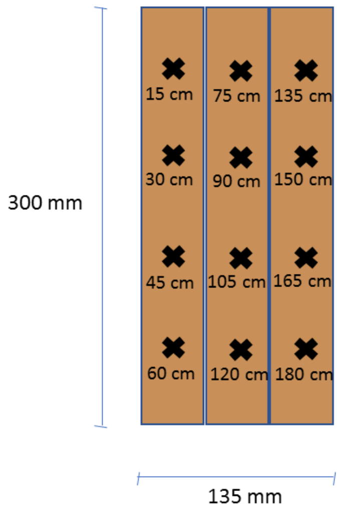


Figure 12 - Sample size of the falling ball test with the heights of drop marked at each position

4.2.3 Janka Hardness

The Janka hardness test aims to determine a measure of the hardness of different types of wood used for wooden flooring. The procedure involves driving a steel ball into the surface of a wooden sample and determining the force required for the ball to penetrate one half its diameter. The procedure stipulated in ASTM D143-14 was followed where a steel ball with a diameter of 11.3 mm was fabricated and a steel pin was fabricated with a groove 5.65 mm deep in order to embed half the steel ball into it shown in Figure 13. The 810 Material Test System (MTS) machine was used to provide an axial force with the specified loading rate of 6mm/min until half the steel ball diameter was penetrated.

The tested samples included Oak, Pine & Casuarina Glauca samples with dimensions specified in the standard of 50mm by 50 mm by 150 mm. 10 samples of each wood type were tested on the radial surface, tangential surface and end surface of the samples shown in Figure 15. The load required to penetrate the steel ball into each surface was recorded to determine the hardness of each type of wood.


Figure 13 - a) 810 Material Test System machine used for driving half the steel ball into the samples. b) Steel ball fabricated as per ASTM D1037.26330 and steel pin fabricated with a groove equal to half the diameter of the steel ball

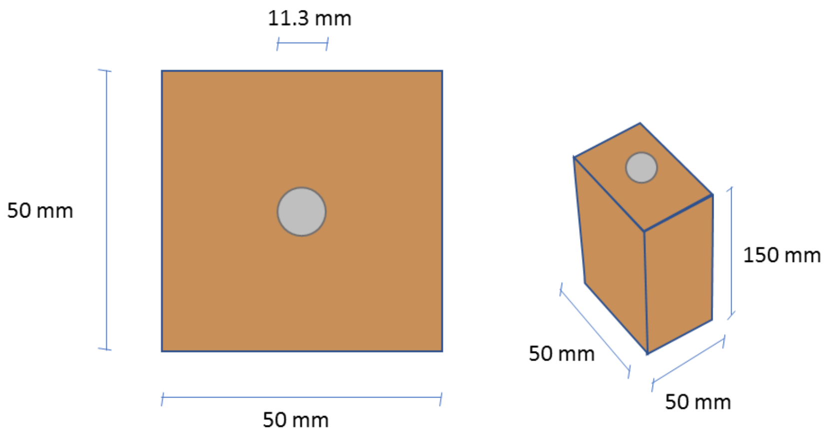


Figure 14 - Sample size and steel ball used in the Janka hardness test

Figure 15 – Janka hardness test assembly, a) test at points 1/2 penetration at radial/tangential sides of sample and b) test at point 3 penetration at end of sample.

4.2.4 Rolling Load

The rolling load test aims to observe the damage to the surface and finishing layer of the wooden floors due to heavy castered objects being moved over the wooden floors. Examples of these heavy loads include pianos, beds and heavy chests, sofas or wardrobes fitted with wheels.

The test procedure involves moving a caster with a superimposed load back and forth along the same path of a wooden strip and measuring the subsequent indentation. Accordingly, a wooden board was manufactured with a centered groove equal to the dimensions of a wooden strip (45 mm wide and 12.5 mm thick). The board also had two grooves at the sides for the wheels of the moving load to be guided into the same path as the load is moved back and forth. The wheels of the moving load were fabricated as per ASTM D2394-17 with a width of 14.3 mm and rounded edges so that the contact surface is 13 mm.

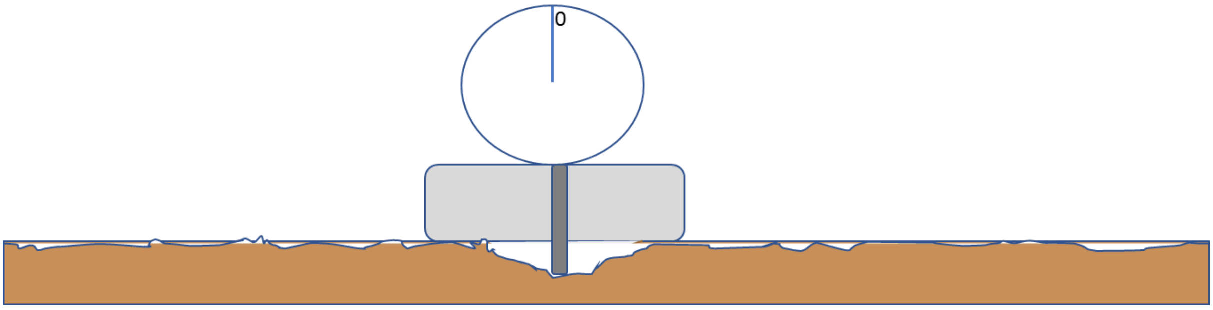


Figure 16 - Indentation Measuring Device

In order to measure the resulting indentation to the samples, an electronic dial gauge with an accuracy of 20 µm and resolution of 0.001 mm was used to measure indentations in the wooden strip. Due to the irregularity in the finished surface of the wood at such high sensitivity of the measuring device, a collar was fabricated with a flat bottom surface to be fitted to the electronic dial gauge and measure the relative indentation on the wood. Figure 16 shows a schematic of the electronic dial gauge fitted with the collar to measure relative indentation while Figure 19 shows the actual shape of the indentation measuring device.

The tested samples included Oak, Pine & Casuarina Glauca samples with one strip to be fitted into the groove in the wooden board. All the samples were tested without coating and with a polyurethane finish, while the Casuarina Glauca samples were also tested with an acrylic polyurethane varnish.

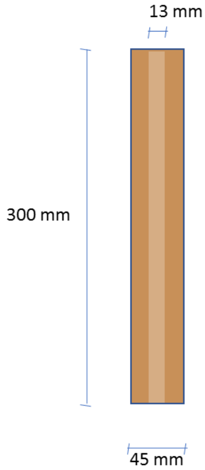


Figure 17 - Sample size of the rolling load test

Figure 18 - Rolling Load test assembly as per ASTM D2394-17

Figure 19 - Digital dial gauge fitted with indentation measuring device to measure relative indentation on wooden sample

4.2.5 Floor surface indentation from small area loads

The floor surface indentation from small area loads test is intended to study the damage caused by small area loads such as women's stiletto heels or objects with sharp edges being stepped onto the floor. Since these objects have an almost infinite value of stress due to their minute contact area, the Casuarina Glauca flooring system is compared with other commercially known floorings to assess if there is a difference in the indentation produced due to the small area loads.

In order to simulate the small area loads, a roller was fabricated according to the ASTM D2394-17standard with a diameter of 97 mm and a length of 46 mm. The roller was fitted with boot caulks which are small steel rods with a diameter of 4 mm projecting 5 mm from the roller to simulate the small area loads. The roller was fabricated with a handle to provide means for pulling the loaded roller and two axles to allow for placing the superimposed loads of 90 kg. The test assembly is shown in Figure 20 below.

The tested samples consisted of Oak, Pine and Casuarina Glauca wooden floors. All the samples were tested without varnish and with a polyurethane varnish, while the Casuarina Glauca samples also had the variation of the acrylic polyurethane varnish. The test procedure was done once with the samples laid perpendicular to the motion of the roller and once parallel to the motion of the roller and the test was repeated twice for each type of wood and each type of varnish as shown in Figure 21.

Figure 20 - Floor surface indentation from small area loads test assembly fabricated as per ASTM D2394-17

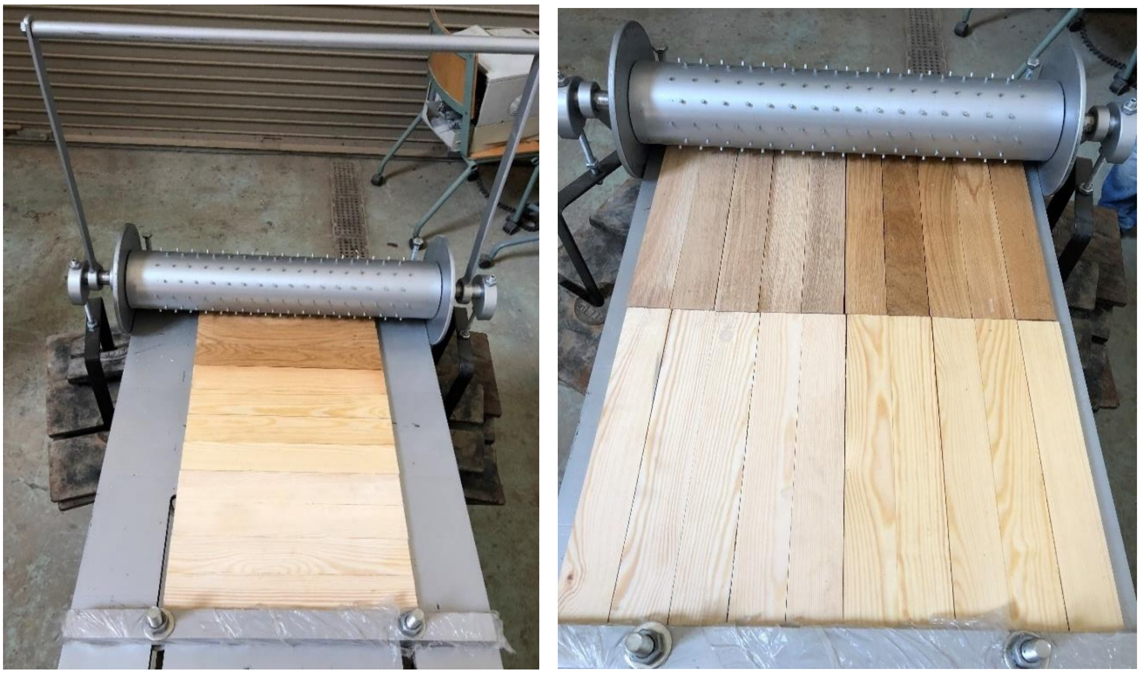


Figure 21 - Oak and Pine Samples laid a) perpendicular and b) parallel to the roller for testing

4.2.6 Surface wetting

The surface wetting test aims to study the behaviour of the wooden floor samples when subjected to wetting such as when water is accidentally spilled on the floor or when there is heavy rain entering from door or window openings. Since wood is a hygroscopic substance and tends to have dimensional changes when exposed to water, cupping distortion is a common behaviour of wood.

The tested samples included Oak, Pine & Casuarina Glauca samples composed of 5 strips to form one tile. All the samples were tested without coating and with a polyurethane finish, while the Casuarina Glauca samples were also tested with an acrylic polyurethane finish. Four samples per wood type per finish were tested in restrained conditions as well as unrestrained conditions as shown in Figure 22. The samples were wetted for 48 hours through wetting a moisture retaining cloth and the restraining action was provided by fixing formwork using nails around each test sample.

Figure 22 - Oak, Pine & Casuarina Glauca samples prepared for the Restrained and Unrestrained Surface wetting test

4.2.7 Coefficient of friction

An important aspect of wooden flooring is the slipperiness of the finished surface which is usually due to the type of finish used. This test aims to determine the coefficient of static friction of the finished wooden flooring samples tested.

The procedure stipulated in the ASTM D2394-17 was followed where a sliding weight of 11.5 kg was wrapped with leather and placed over a shimmed tile of wooden flooring sample. The sliding weight was tied to a pulley with an electronic scale in between to measure the tension in the cable which does not stretch significantly and the force was recorded the moment the sliding weight was moved shown in Figure 23.

The tested samples included Oak, Pine & Casuarina Glauca samples composed of 5 strips to form one tile. All the samples were tested without coating and with a polyurethane finish, while the Casuarina Glauca samples were also tested with an acrylic polyurethane finish. Four samples per wood type per finish were tested. The coefficient of static friction was then determined by dividing the force required to move the sliding weight by the mass of the sliding weight.

Figure 23 - Coefficient of friction test assembly consisting of a pulley, electronic scale and sliding weight covered with leather

4.2.8 Abrasion Resistance

The abrasion test is intended to study the abrasion resistance of the wooden flooring samples with different types of coatings to determine the suitability of using these finishes in heavy traffic areas and in order to estimate the maintenance needs of different types of finish.

THE ASTM D2394-17 specifies the Navy-Type Wear Tester machine for measuring the abrasion of the wooden flooring samples. However, due to the unavailability of this machine, an alternative setup was proposed to measure the resistance of abrasion where a motor with a rotating disk was fitted with Aluminium Oxide grinding paper and the samples were brought to contact the grinding paper for a set duration corresponding to 500 revolutions as specified in the ASTM standard as shown in Figure 24.

The tested samples included Oak, Pine & Casuarina Glauca wooden samples with dimensions of 50 mm by 50 mm by 12.5 mm (similar to the thickness of the proposed wooden flooring system design) as shown in Figure 25 & Figure 26. The samples were then glued in pairs due to the difficulty in handling the 12.5 mm thick samples and were weighed before gluing, after gluing and after abrading on each side in order to determine the lost weight on each sample. All types of wood were tested without coating, with polyurethane coating and with acrylic polyurethane coating.

Figure 24 - Equipment fitted with abrading sand paper (0.6mm Fiber Paper Aluminum Oxide/Silicon Carbide Fiber Disc Kf807)

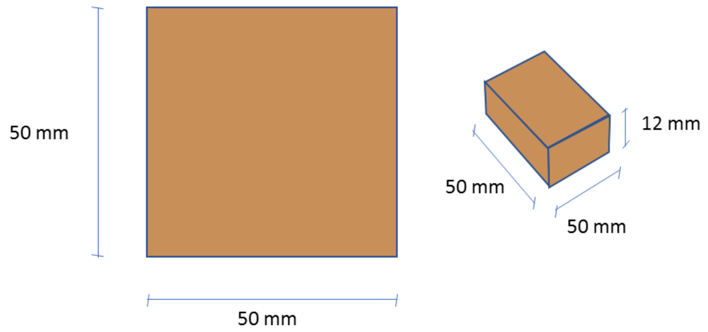


Figure 25 - Sample size of the abrasion test

Figure 26 - Oak, Pine and Casuarina Glauca samples with different types of coating prepared for testing

4.2.9 Resistance to Staining & Cigarette Burns

The cigarette burns and resistance to staining tests are usually performed on laminate flooring systems as per EN438-2 where the samples are subjected to cigarette burns and staining agents such as acetone, coffee, ink, Sodium Hydroxide (present in soaps) and Hydrogen Peroxide (present in bleaching agents) in order to simulate the damage to the wooden flooring surface if it is accidentally exposed to these agents.

The test involves placing a few drops of each of the aforementioned substances and visually assessing the damage to the gloss/colour of the samples after being in contact for a set time. The tested samples included Oak, Pine & Casuarina Glauca samples and photographs of the result were reported.

CHAPTER 5: RESULTS AND DISCUSSION

This chapter discusses the results obtained from each test in the form of graphs, tables and photographic images. Followed by analysis and comparison of the test outcomes of the different types of wood and different coatings used for the samples.

5.1 Analysis of results

In order to study the differences in the performance of the different types of wooden flooring systems with variations in wood type (Oak, Pine & Casuarina Glauca) and type of finish (Polyurethane, Acrylic Polyurethane or no coating), a set of statistical tests have been performed. The statistical tests aim to determine if the data samples have equal averages, meaning that there is no significant statistical difference between the results.

It is clear from the results plotted in the form of a box plot that the performance of the Pine wooden flooring systems was apparently lower than the Oak and Casuarina Glauca samples in all tests. However, the Oak and Casuarina Glauca samples had similar results which required statistical means to determine if they actually had similar results or the performance of one was better than the other.

In order to so, the t-test is done using the Data Analysis ToolPak add-in on Microsoft Excel 2017 for the two data samples to check if there is a significant statistical difference between the averages by proposing a null hypothesis (which is that the two samples have equal means or the difference between the two means is equal to 0) and checking if there is enough statistical evidence to reject this null hypothesis through comparing the statistical t-value and the critical t-value or by comparing the calculated significance P-value with the cut-off significance based on the confidence interval (0.05 in the case of 95% confidence). If the statistical t-value is larger than the critical t-value, we have enough statistical evidence to reject the null hypothesis which means that the two samples do not have equal means. While if the statistical t-value is lower than the critical t-value, it means we do not have enough statistical evidence to reject the null hypothesis, that the two samples have equal means. The decision can also be done through the significance P-value where if the P-value is lower than the cut-off significance interval of the test (0.05 for 95% confidence), we may reject the null hypothesis and vice versa.

However, there are two types of T-tests for comparing means of two samples, one is assuming equal variances for the two data sets and the other is assuming unequal variances. To determine which T-test to use, the F-test for variances is performed to determine if the variances can be assumed to be equal or not. Similar to the t-test, a null hypothesis is also proposed that is the two data samples have equal variances (or the difference between the variances is null or 0) and the null hypothesis may be rejected if the statistical F-value is greater than the critical F-value or if the significance P is lower than the significance cut-off (0.05 for 95% confidence). Therefore, by carrying out the F-test on the variances of the Oak and Casuarina Glauca data samples, we are able to determine whether to use the t-test: assuming unequal variances or the t-test: assuming equal variances to determine whether there is a statistical difference in their averages.

Another statistical test performed is the ANOVA or the Analysis of Variance test which helps us identify if there are differences between the average measurements of the samples or if a certain pairing in the groups has significantly different averages. Similar to the t-test, a null hypothesis is also proposed that is the two data samples have equal averages (or the difference between the averages is null or 0) and the null hypothesis may be rejected if the statistical F-value is greater than the critical F-value or if the significance P is lower than the significance cut-off (0.05 for 95% confidence). There is the Single-Factor ANOVA and Two-Factor ANOVA depending on the data set. The Single-Factor ANOVA was initially performed to determine if there is a statistical difference due to the different types of finishes used (ie. Polyurethane, Acrylic polyurethane and no coating). If no significant statistical difference between the different types of finished, the types of wood were compared directly with each other. However, if there was a significant difference between the averages of the different types of finish, a Two-Factor ANOVA was performed to check if there is a significant difference between the types of finish, the types of wood and if there are any statistical interactions between the types of finish and types of wood.

Furthermore, regression analysis was performed for the results of the Falling ball indentation test to determine if there is a correlation between the independent variable (height of drop of the ball) and the dependent variable (indentation). The scatter plot of the averages of the indentation for each type of wood and each type of finish depicted a linear best fit and that was validated through the R^2 coefficient which showed values close to 1 indicating positive correlation.

5.1.1 Concentrated Loading

The results for the concentrated load test were obtained from the MTS machine for points 1 (top left) and 2 (center) of all the samples as shown in Figure 9. A load-deformation curve was plotted for each sample and a polynomial best fit line was plotted for interpolation and the equivalent formula was used to obtain the displacement corresponding to the 4.45 kN load specified in the ASTM standard as shown in Figure 28, Figure 29 & Figure 30. Comparison between the indentation at point 1 and point 2 of all the samples was made as depicted in Figure 31 showing the variance and mean of the indentations. The average indentation at point 1 was highest in the Pine samples corresponding to 1.5 mm in both the finished and unfinished samples. Followed by the Oak samples with average indentation of 0.96 mm and the least average indentation was in the Casuarina Glauca samples with 0.81 mm indentation corresponding to the 4.45 kN axial force. While at point 2, the Oak samples had the least average indentation of 0.66 mm followed closely by the Casuarina Glauca samples with 0.81 mm average indentation and the highest was the Pine samples with a 2.13 mm average indentation. Residual indentation was also measured after 1h of testing as specified in the ASTM standard, the comparison between the different samples is shown in Figure 32. It is clear that there is a significant drop in the values of the indentation due to the load being in the elastic region of deformation and hence, the wooden samples recovered most of the indentation produced by the load. The same trend in the results was observed among the different types of wood with Pine samples having the highest residual indentation followed by the Oak samples and then closely followed by the Casuarina Glauca samples. It is worth noting that the Casuarina Glauca samples had very minimal residual indentations ranging between 0.01 and 0.03 mm which shows how the wooden flooring is able to retain its surface properties after being subjected to concentrated loads.

It was apparent through graphical representation that the Pine samples had significantly higher indentations however, to determine if the difference between the Oak and Casuarina Glauca samples was significant, the following test statistics were made. First, a Single Factor ANOVA was done between the different types of finishes in the Casuarina and Oak samples as shown in Table 3 and Table 4. The results showed that we cannot reject the null hypothesis therefore, there is no significant difference due to the type of finish in the Casuarina and Oak samples. An F-test was done next for point 1 and point 2 to determine if we should assume equal or unequal variances in the t-test. As shown in Table 5 and Table 6. Point 1 indicated equal variances while Point 2 indicated unequal variances since the statistical F-value was higher than the critical F-value meaning that there is significant statistical difference in the variances of the Casuarina and Oak samples. Accordingly, the t-test was done for point 1 assuming unequal variances and point 2 assuming unequal variances as shown in Table 7 and Table 8, and the results showed that although there is a difference in the values of the means of the Casuarina and Oak samples in points 1 and 2, we do not have enough statistical evidence to reject the null hypothesis and the means of the two samples are assumed to be equal. Therefore, it can be concluded that for the concentrated load test at points 1 and 2, the Pine samples had the highest indentation indicating the least resistance to heavy loads while the Oak and Casuarina Glauca samples had significantly lower indentations and are assumed to be the same in terms of resistance to heavy loads. The type of finish had no significant impact on the resistance of the samples to heavy concentrated loads.

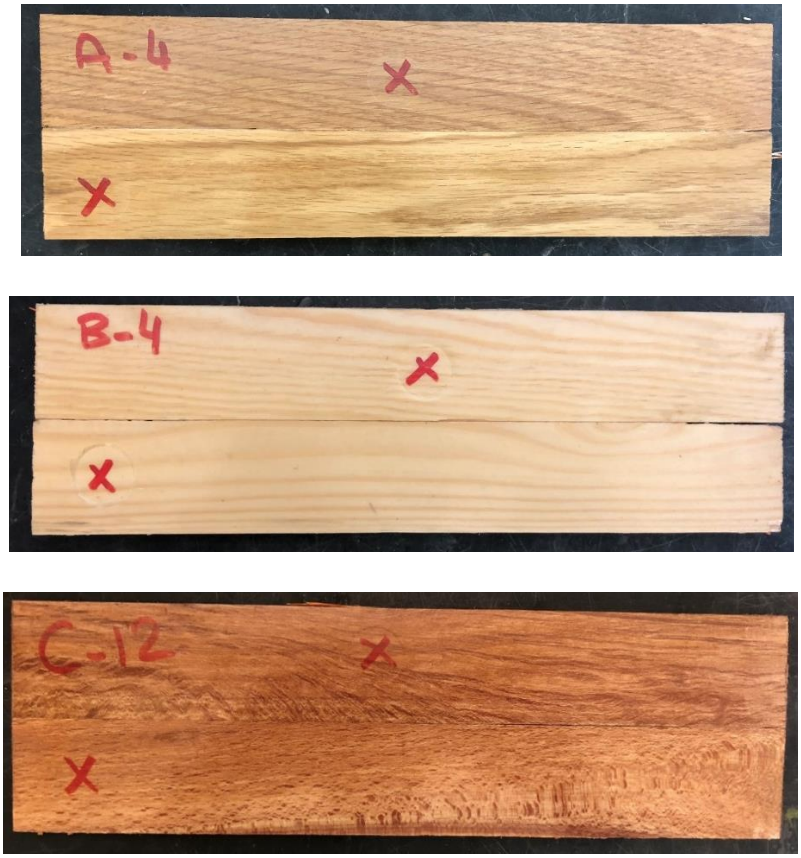


Figure 27 - One of the Oak, Pine & Casuarina Glauca samples after testing showing the indentations marked with an "X" for subsequent measurement at points 1 & 2 (top left and center of the specimen)

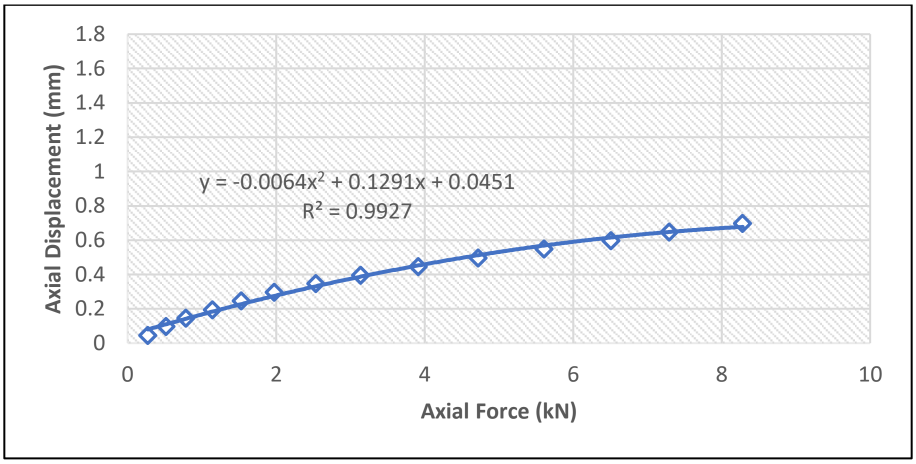


Figure 28 - Load Deformation curve for one of the Oak samples

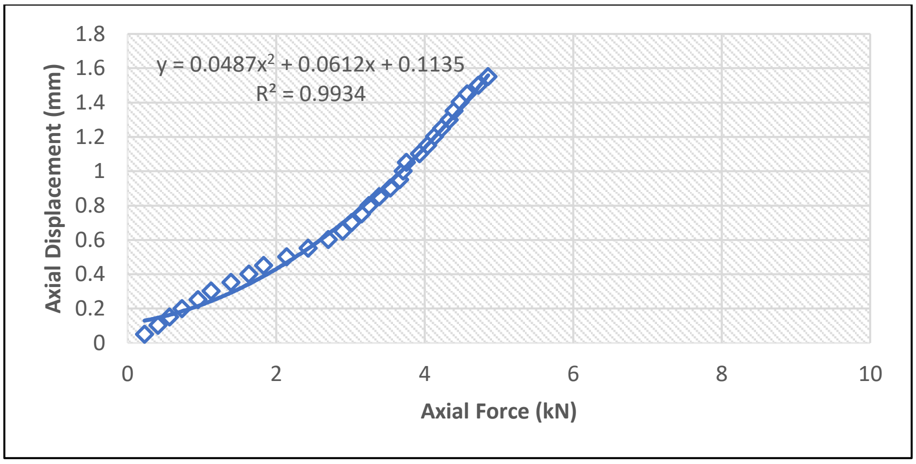


Figure 29 - Load Deformation curve for one of the Pine samples

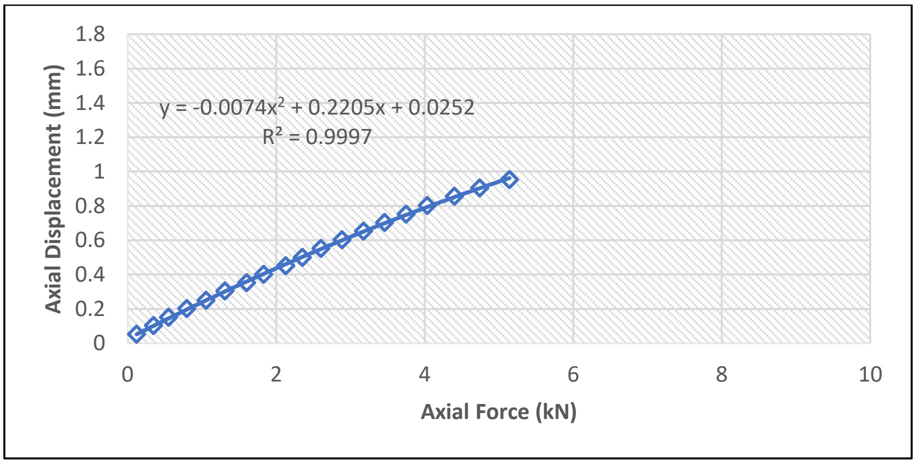
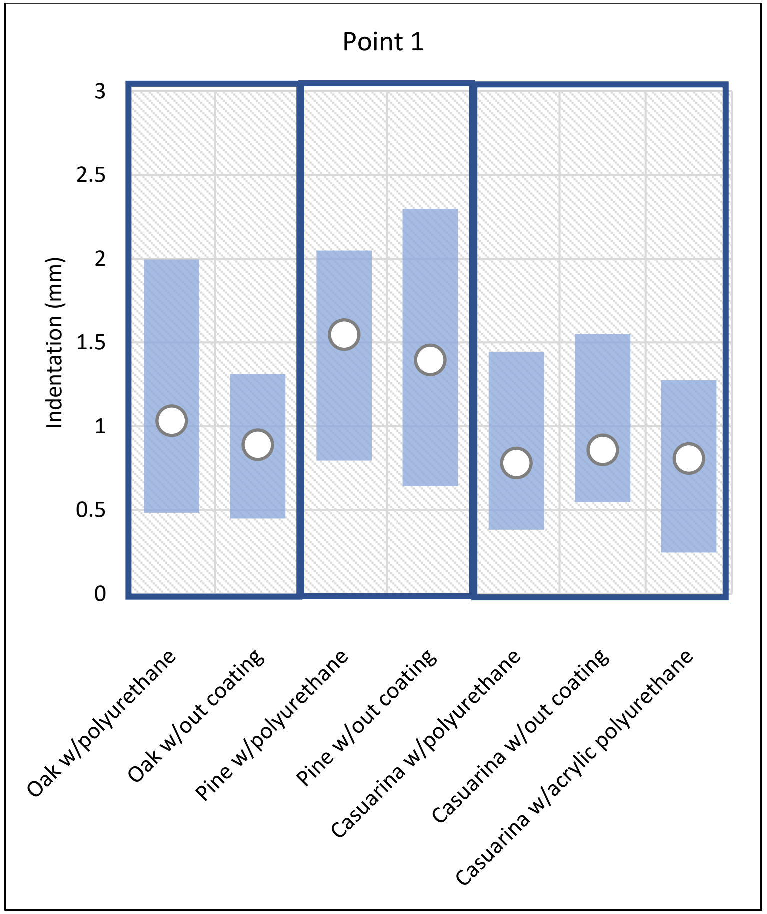


Figure 30 - Load Deformation curve for one of the Casuarina Glauca samples



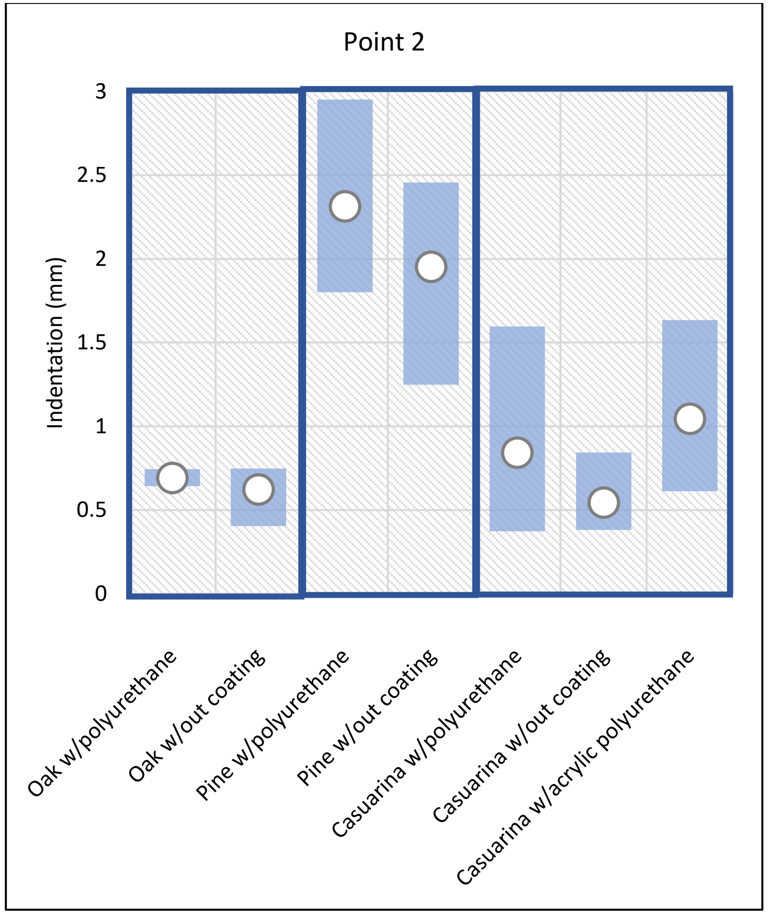


Figure 31 - Comparison between indentation at point 1 and point 2) of the Oak, Pine & Casuarina Glauca samples

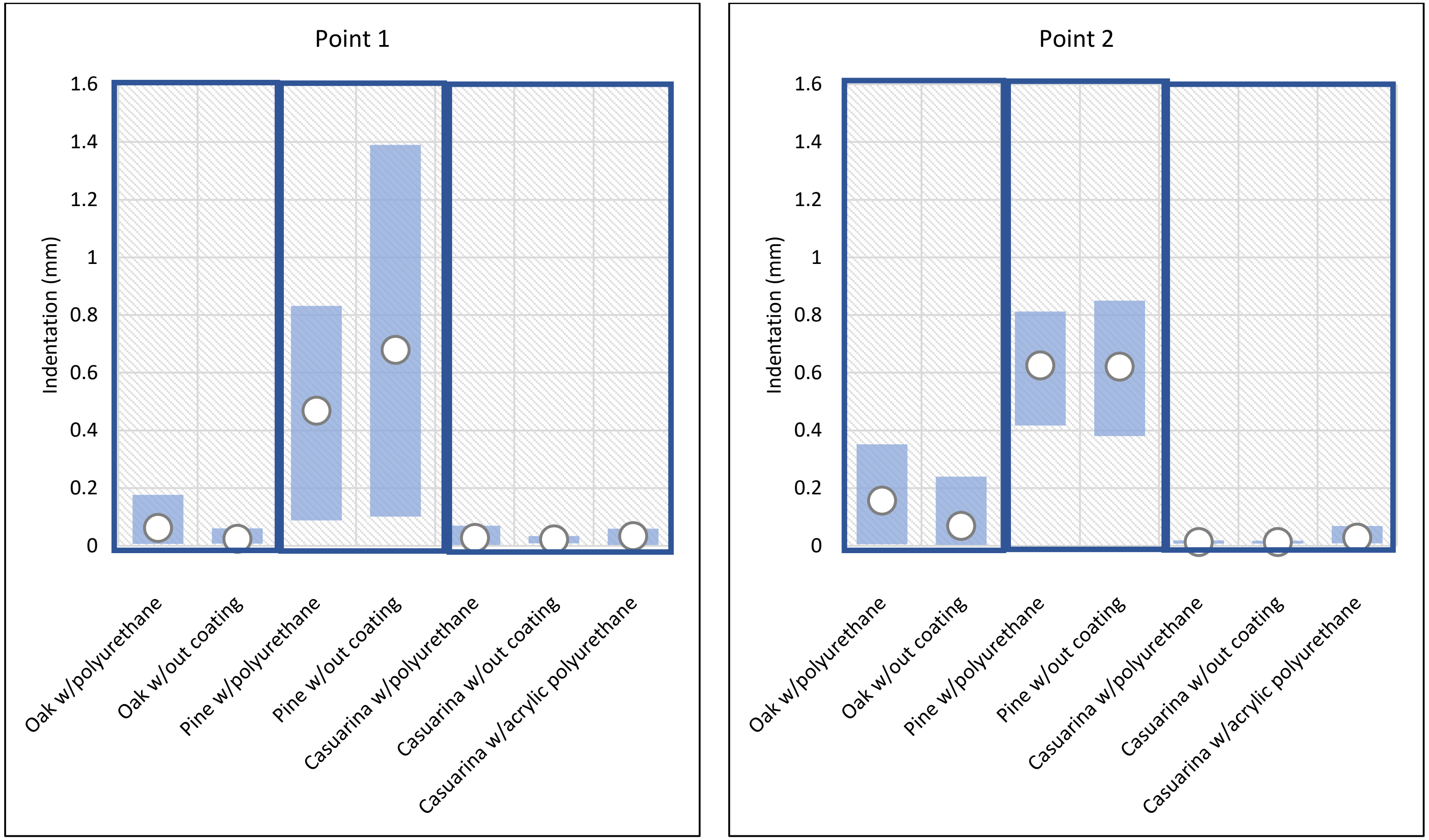


Figure 32 - Comparison between residual indentation at point 1 and point 2 of the Oak, Pine & Casuarina Glauca samples

Table 3 - ANOVA for Casuarina samples

Anova: Single Factor (Casuarina)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Finish 1	4	3.125	0.78125	0.248425
Unfinished	4	3.432	0.858	0.224042
Finish 2	4	3.227	0.80675	0.179214

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.012223	2	0.006112	0.028135	0.972343	4.256495
Within Groups	1.955044	9	0.217227			
Total	1.967267	11				

Table 4 - ANOVA for Oak samples

Anova: Single Factor (Oak)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Finish 1	4	4.13	1.0325	0.478759
Unfinished	4	3.558	0.8895	0.158438

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.040898	1	0.040898	0.128369	0.732398	5.987378
Within Groups	1.91159	6	0.318598			
Total	1.952488	7				

Table 5 - F-test at point 1

F-Test Two-Sample for Variances (Point 1)

	Oak	*Casaurina*
Mean	0.961	0.815333
Variance	0.278927	0.178842
Observations	8	12
df	7	11
F	1.559624	
P(F<=f) one-tail	0.244737	
F Critical one-tail	3.758638	

Table 6 - F-test at Point 2

F-Test Two-Sample for Variances (Point 2)

	Casaurina	*Oak*
Mean	0.91	0.656375
Variance	0.240198	0.013285
Observations	12	8
df	11	7
F	18.08023	
P(F<=f) one-tail	0.000426	
F Critical one-tail	4.70947	

Table 7 - t-test at Point 1

t-Test: Two-Sample Assuming Equal Variances (Point 1)

	Oak	*Casaurina*
Mean	0.961	0.815333
Variance	0.278927	0.178842
Observations	8	12
Pooled Variance	0.217764	
Hypothesized Mean Difference	0	
df	18	
t Stat	0.683892	
P(T<=t) one-tail	0.251377	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.502753	
t Critical two-tail	2.100922	

Table 8 - t-test at Point 2

t-Test: Two-Sample Assuming Unequal Variances (Point 2)

	Casaurina	*Oak*
Mean	0.91	0.656375
Variance	0.240198	0.013285
Observations	12	8
Hypothesized Mean Difference	0	
df	13	
t Stat	1.722626	
P(T<=t) one-tail	0.054322	
t Critical one-tail	1.770933	
P(T<=t) two-tail	0.108644	
t Critical two-tail	2.160369	

5.1.2 Falling ball indentation

The results of the falling ball test involved measuring the indentation caused by various dropped heights of a steel ball to determine the resistance of the wooden floors to impact loads caused by falling objects as shown in Figure 33, Figure 34 & Figure 35. The indentation measuring device was used to record the indentation caused by the steel ball at each height and the results were plotted in a scatter diagram as shown in Figure 36, the averages for each type of wood and each type of finish was plotted in Figure 37. A linear best fit was also plotted for each type of samples in order to study the correlation between the increased heights of the dropped ball and the indentation caused. The linear plots showed positive correlation with R^2 values ranging from 85% to 99% meaning that the as the independent variable (height of drop) increases, the independent variable (indentation) increases. The steeper lines indicated higher resistance since the increased heights of dropped ball resulted in small indentations on the x-axis and these corresponded to the Casuarina Glauca samples. After which came the Oak samples with slightly less steep lines. The Pine samples had the least resistance to impact since they corresponded to the least steep lines in the plot. In order to determine whether the difference in the resistance between the Casuarina Glauca and Oak samples was significant, a Two-Factor ANOVA was performed on the Casuarina and Oak samples with different finished as shown in Table 16. The data fields used were the slopes of the best fit lines of the scatter plot. The results showed that the statistical F-values in the type of wood, type of finish and interaction between them are less than the critical F-values therefore we do not have enough evidence to reject the null hypothesis and there is no significant difference between the means of both samples. Also, to determine if the type of finish had an impact on the resistance of the wood, a Single-Factor ANOVA was performed on the Casuarina Glauca samples and there wasn’t enough evidence to reject the null hypothesis as shown in Table 17.

Hence, it was found that the Casuarina Glauca and the Oak samples had the highest impact resistance with no significant difference between them followed by the Pine samples noting that the type of finish had no significant impact on the performance of the samples in terms of impact resistance.

Figure 33 - Oak samples after the falling ball test showing indentation caused by dropping the ball from different heights to be measured using the indentation measuring device

Figure 34 - Pine samples after the falling ball test showing indentation caused by dropping the ball from different heights to be measured using the indentation measuring device

Figure 35 – Casuarina Glauca samples after the falling ball test showing indentation caused by dropping the ball from different heights to be measured using the indentation measuring device

Table 9 - Indentation measurements at different dropped ball heights for Oak samples coated w/ polyurethane

Height of Drop (cm)	A-1	A-2	A-3	A-4	Average Indentation (mm)
	Dial Gauge Reading	Dial Gauge Reading	Dial Gauge Reading	Dial Gauge Reading	
15	0.133		0.2	0.13	0.154
30	0.237	0.212	0.215	0.167	0.208
45	0.289	0.292	0.241	0.225	0.262
60	0.362	0.36	0.259	0.281	0.316
75	0.175	0.296	0.269	0.292	0.258
90	0.218	0.305	0.308	0.3	0.283
105	0.305	0.376	0.24	0.297	0.305
120	0.426	0.336	0.334	0.444	0.385
135	0.453	0.329	0.373	0.386	0.385
150	0.467	0.419	0.475	0.39	0.438
165	0.493	0.415	0.416	0.35	0.419
180	0.564	0.423	0.443	0.418	0.462

Table 10 - Indentation measurements at different dropped ball heights for Oak samples w/out coating

Height of Drop (cm)	A-5 Dial Gauge Reading	A-6 Dial Gauge Reading	A-7 Dial Gauge Reading	A-8 Dial Gauge Reading	Average Indentation (mm)
15	0.133		0.32	0.32	0.258
30		0.131	0.157		0.144
45	0.22	0.202	0.148	0.105	0.169
60	0.231	0.295	0.201	0.195	0.231
75	0.25	0.24	0.249	0.333	0.268
90	0.278	0.236	0.253	0.334	0.275
105	0.177	0.281	0.37	0.378	0.302
120	0.234	0.239	0.391	0.387	0.313
135	0.345	0.395	0.459	0.406	0.401
150	0.44	0.323	0.552	0.455	0.443
165	0.34	0.296	0.559	0.47	0.416
180	0.475	0.409	0.582	0.533	0.500

Table 11 - Indentation measurements at different dropped ball heights for Pine samples coated w/ polyurethane

Height of Drop (cm)	B-1 Dial Gauge Reading	B-2 Dial Gauge Reading	B-3 Dial Gauge Reading	B-4 Dial Gauge Reading	Average Indentation (mm)
15	0.171	0.208	0.19	0.187	0.189
30	0.271	0.313	0.215	0.207	0.252
45	0.438	0.44	0.4	0.43	0.427
60	0.542	0.469	0.61	0.523	0.536
75	0.612	0.533	0.624	0.71	0.620
90	0.705	0.586	0.716	0.802	0.702
105	0.62	0.61	0.636	0.838	0.676
120	0.819	0.64	0.801	1.019	0.820
135	0.844	0.85	1	0.825	0.880
150	0.76	0.82	1.037	0.852	0.867
165		0.872	1.044	0.887	0.934
180	0.929	1.06	1.188	0.932	1.027

Table 12 - Indentation measurements at different dropped ball heights for Pine samples w/out coating

Height of Drop (cm)	B-5 Dial Gauge Reading	B-6 Dial Gauge Reading	B-7 Dial Gauge Reading	B-8 Dial Gauge Reading	Average Indentation (mm)
15	0.104	0.117	0.205	0.29	0.179
30	0.19	0.228	0.404	0.269	0.273
45	0.43	0.33	0.52	0.412	0.423
60	0.556	0.419	0.44	0.427	0.461
75	0.61	0.476	0.54	0.644	0.568
90	0.632	0.676	0.574	0.692	0.644
105	0.566	0.485	0.78	0.59	0.605
120	0.661	0.64	0.84	0.6	0.685
135	0.459	0.73	0.74	0.656	0.646
150	0.553	0.745	0.769	0.724	0.698
165	0.704	0.775	0.805	0.55	0.709
180	0.734	0.993	0.935	0.758	0.855

Table 13 - Indentation measurements at different dropped ball heights for Casuarina Glauca samples coated w/ polyurethane

Height of Drop (cm)	C-1 Dial Gauge Reading	C-2 Dial Gauge Reading	C-3 Dial Gauge Reading	C-4 Dial Gauge Reading	Average Indentation (mm)
15	0.001	0.011	0.015	0.008	0.009
30	0.054	0.025	0.088	0.022	0.047
45	0.102	0.099	0.113	0.05	0.091
60	0.152	0.172	0.211	0.097	0.158
75	0.176	0.108	0.235	0.103	0.156
90	0.222	0.319	0.237	0.088	0.217
105	0.131	0.316	0.29	0.177	0.229
120	0.168	0.482	0.321	0.171	0.286
135	0.328	0.311	0.324	0.255	0.305
150	0.358	0.466	0.354	0.291	0.367
165	0.438	0.507	0.435	0.302	0.421
180	0.57	0.433	0.509	0.419	0.483

Table 14 - Indentation measurements at different dropped ball heights for Casuarina Glauca samples w/out coating

Height of Drop (cm)	C-5 Dial Gauge Reading	C-6 Dial Gauge Reading	C-7 Dial Gauge Reading	C-8 Dial Gauge Reading	Average Indentation (mm)
15	0.009	0.013	0.032	0.03	0.021
30	0.034	0.04	0.085	0.04	0.050
45	0.039	0.118	0.119	0.081	0.089
60	0.138	0.149	0.131	0.143	0.140
75	0.227	0.108	0.212	0.113	0.165
90	0.411	0.145	0.201	0.241	0.250
105	0.303	0.224	0.207	0.158	0.223
120	0.233	0.264	0.271	0.194	0.241
135	0.308	0.3	0.15	0.316	0.269
150	0.205	0.288	0.192	0.401	0.272
165	0.428	0.366	0.267	0.326	0.347
180	0.308	0.329	0.236	0.357	0.308

Table 15 - Indentation measurements at different dropped ball heights for Casuarina Glauca samples coated w/ acrylic polyurethane

Height of Drop (cm)	C-9 Dial Gauge Reading	C-10 Dial Gauge Reading	C-11 Dial Gauge Reading	C-12 Dial Gauge Reading	Average Indentation (mm)
15	0.029	0.016	0.016	0.02	0.020
30	0.052	0.026	0.04	0.056	0.044
45	0.059	0.032	0.047	0.08	0.055
60	0.062	0.079	0.063	0.083	0.072
75	0.058	0.205	0.107	0.106	0.119
90	0.201	0.265	0.127	0.149	0.186
105	0.208	0.295	0.161	0.169	0.208
120	0.135	0.494	0.215	0.192	0.259
135	0.201	0.302	0.163	0.247	0.228
150	0.26	0.227	0.134	0.256	0.219
165	0.293	0.51	0.257	0.282	0.336
180	0.309	0.27	0.235	0.345	0.290

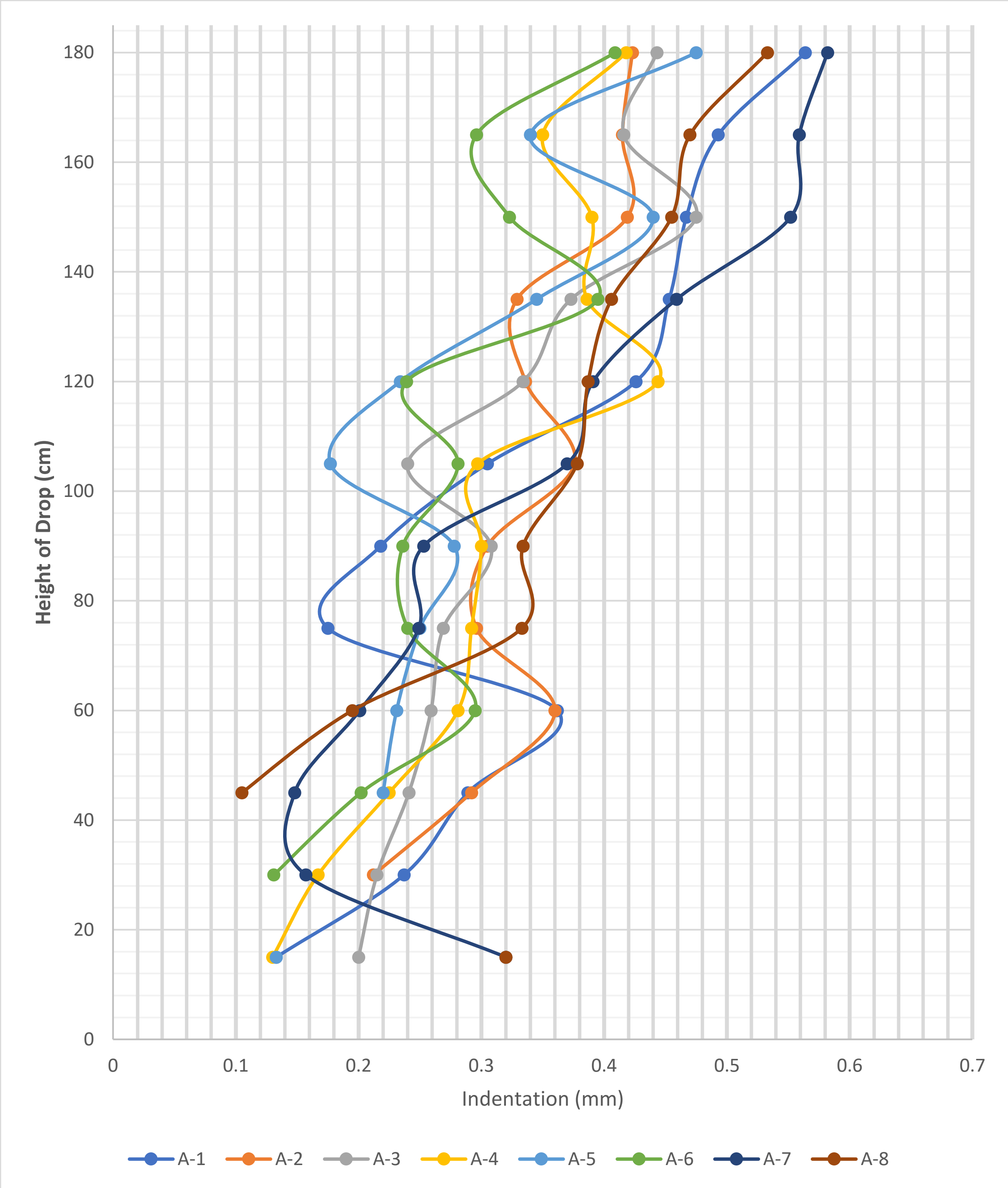


Figure 36 - Indentation of Oak samples due to different heights of dropped ball

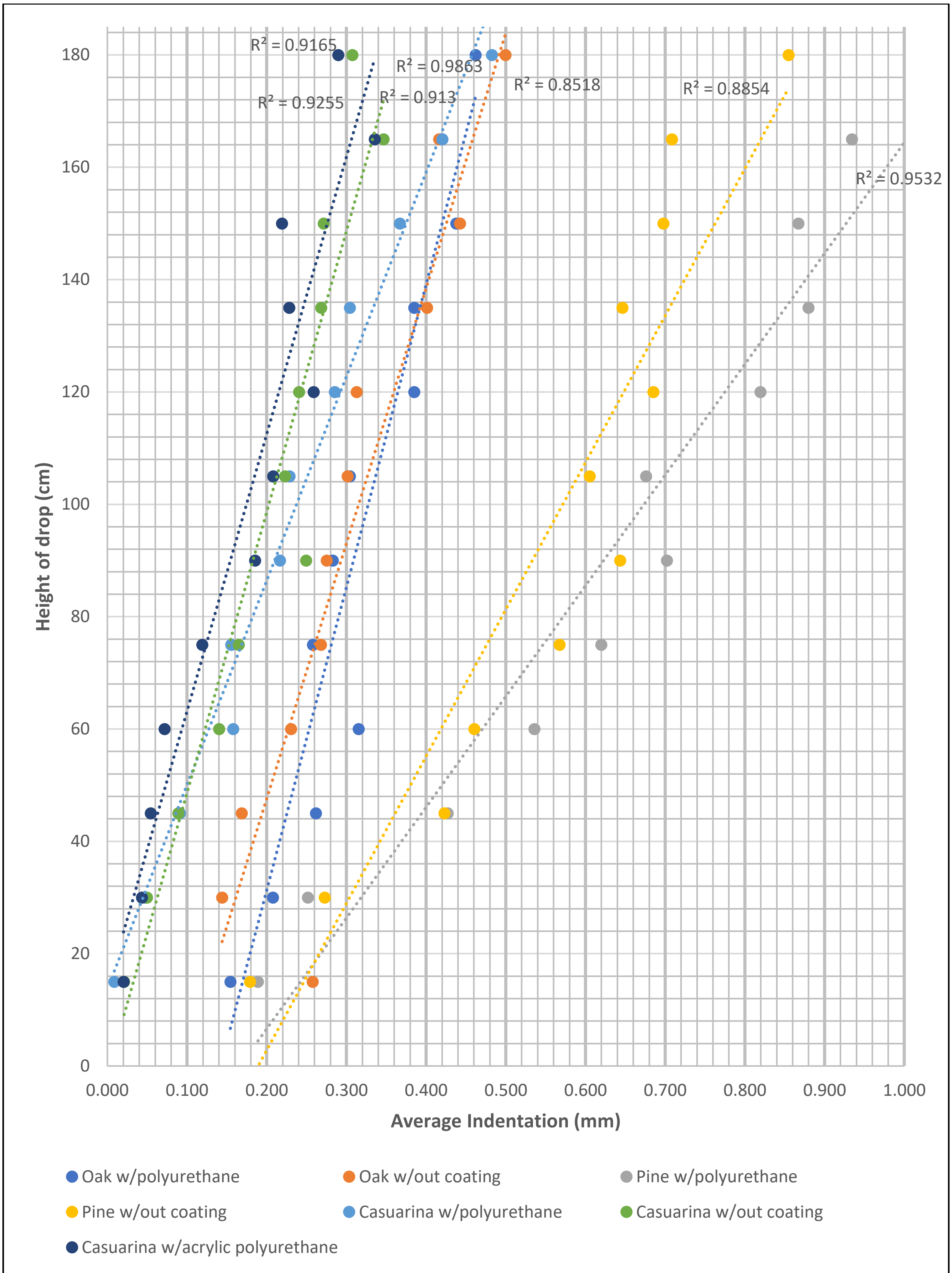


Figure 37 – Average indentation of Oak, Pine & Casuarina Glauca samples due to different heights of dropped ball

Table 16 - Two-Factor ANOVA between different types of wood and different finishing

SUMMARY	Unfinished	Finish 1	Total
Casuarina			
Count	4	4	8
Sum	1741.673	1353.908	3095.581
Average	435.4182	338.4771	386.9476
Variance	15275.76	3822.996	10870.2
Oak			
Count	4	4	8
Sum	1572.093	2019.94	3592.033
Average	393.0233	504.985	449.0041
Variance	6548.236	15548.05	13051.39
Total			
Count	8	8	
Sum	3313.766	3373.848	
Average	414.2207	421.7311	
Variance	9866.663	16223.28	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Type of wood	15404.04	1	15404.04	1.495718	0.244807	4.747225
Type of finish	225.6196	1	225.6196	0.021907	0.884792	4.747225
Interaction	43640.41	1	43640.41	4.237443	0.061934	4.747225
Within	123585.1	12	10298.76			
Total	182855.2	15				

Table 17 - Single Factor ANOVA for the type of finish in Casuarina samples

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
296.9598662	3	1444.713	481.571	10133.16
299.7440256	3	1054.164	351.3881	4734.328
495.0169267	3	1413.515	471.1717	37709.32

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	31403.84	2	15701.92	0.895942	0.45659	5.143253
Within Groups	105153.6	6	17525.6			
Total	136557.5	8				

5.1.3 Janka Hardness

The Janka hardness involves determining the hardness of the wood on the tangential, radial and end surfaces of the wood specimens as shown in Figure 38 below. Through the graphical comparison of the results shown in Figure 40, we are able to conclude that the hardness of the Pine samples is significantly lower than the Oak and Casuarina Glauca samples in the tangential, radial and end surface tests for hardness. The tangential and radial surfaces seem to have the same results while the end surface seems to have smaller values possibly due to the force being applied in a direction parallel to the grain of wood at that surface.

To be able to determine if the difference in the results between both the Casuarina Glauca and Oak samples and the different test surfaces of the hardness test, a Two-Factor ANOVA was performed as shown in Table 18. Based on the results, it is shown that the statistical F-value for the type of wood is higher than the critical F-value which means that we have enough statistical evidence to reject the null hypothesis and the difference in the means of the type of wood is significant (11.4 kN for Casuarina vs. 8.4 kN for Oak). While the statistical F-value for the different surfaces of the test and the interactions between the different wood types and test surfaces was lower than the critical F-values which means that there is no evidence enough to reject the null hypothesis and hence, there is no significant difference between the results. Therefore, it can be concluded that the Casuarina Glauca samples had significantly higher values of hardness when compared to the Oak and Pine samples.

Figure 38 - Oak, Pine & Casuarina Glauca samples after the Janka hardness test

Figure 39 - Janka hardness test results at the tangential, radial and end surfaces of the samples

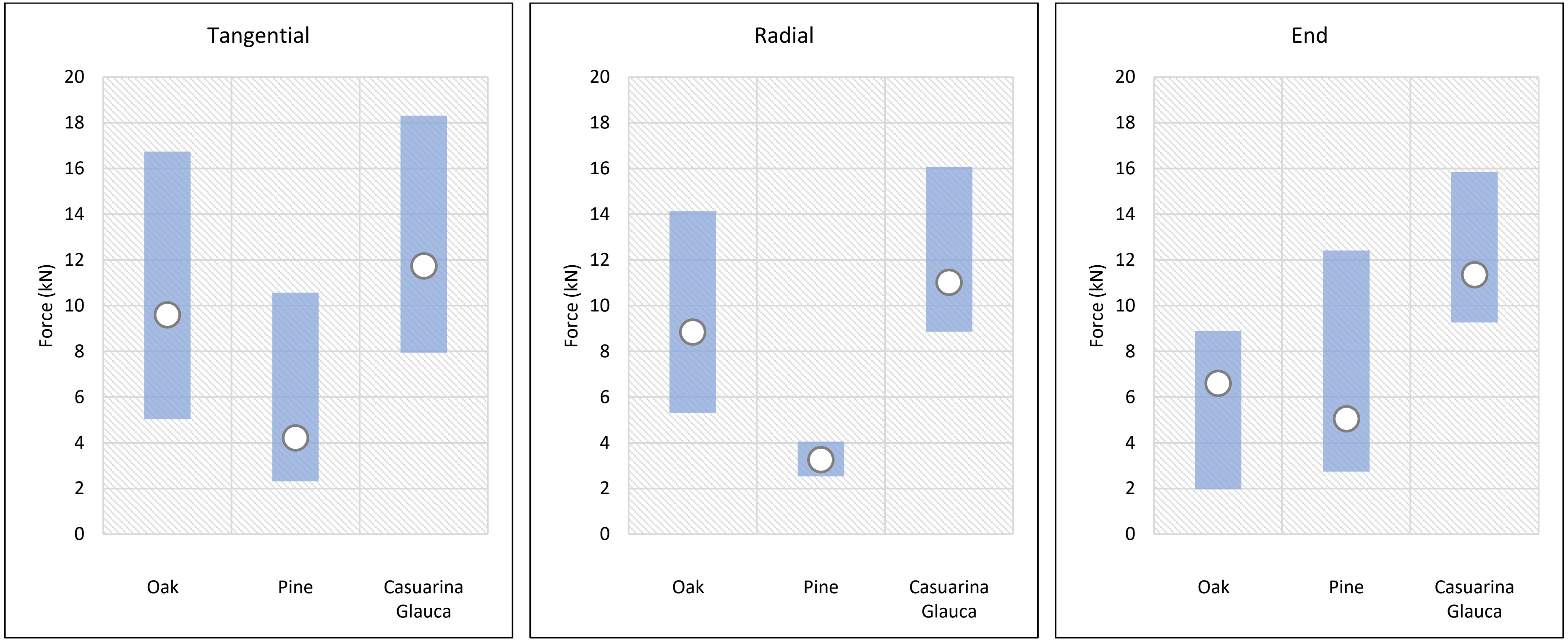


Figure 40 - Comparison of the force required to drive half the diameter of the steel ball into the tangential surface, radial surface & end of the Oak, Pine & Casuarina Glauca samples

Table 18 - Two-Factor ANOVA for the different types of wood and different test surfaces

Anova: Two-Factor With Replication

SUMMARY	Tangential	Radial	End	Total
Casuarina				
Count	10	10	10	30
Sum	117.426	110.299	113.544	341.269
Average	11.7426	11.0299	11.3544	11.37563
Variance	9.156082	4.757472	5.740642	6.187388
Oak				
Count	10	10	10	30
Sum	96.053	88.558	66.097	250.708
Average	9.6053	8.8558	6.6097	8.356933
Variance	15.47879	8.119696	4.024638	10.24859
Total				
Count	20	20	20	
Sum	213.479	198.857	179.641	
Average	10.67395	9.94285	8.98205	
Variance	12.87127	7.343583	10.54992	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Type of Wood	136.6882	1	136.6882	17.34721	0.000113	4.019541
Surface of test	28.80113	2	14.40056	1.827586	0.170607	3.168246
Interaction	22.34646	2	11.17323	1.418003	0.251071	3.168246
Within	425.4959	54	7.879554			
Total	613.3317	59				

5.1.4 Rolling Load

The rolling load test results include indentation produced by the front caster of the roller after 10, 25 and 50 trips (50 trips only if the indentation after 25 trips was less than 0.25 mm). Three positions were marked on each sample, near the top, center and bottom of the sample and an average value was taken for calculations. Initial readings were taken using the indentation measuring device before testing to account for the irregularity in the finished floor surface. The indentation measuring device was used to take readings after 10, 25 & 50 trips if necessary and the initial reading was deducted from the final readings to determine the indentation due to the rolling load solely. Figure 41, Figure 42 & Figure 43 show the indentation on the different samples upon testing. It is clear that the Pine samples had the most vivid indentation marked by the path of the rolling load, while the Oak & Casuarina Glauca samples had minor or no marks which shows their high resistance to heavy rolling loads.

It is graphically vivid in Figure 44, Figure 45 & Figure 46 comparing the results of the indentation damage after 10, 25 and 50 trips that there is a huge difference between the indentation in Pine samples when compared to the Oak and Casuarina Glauca samples. There is also a large variation in the results of indentation in the Pine samples with values ranging from around 0.07 to 0.48 mm while the Oak & Casuarina Glauca samples have minimal variation between 0 and 0.05 mm. The average indentation in each type of sample depict that Pine samples with and without coating are approximately 0.26 mm after 10 trips and 0.35 mm after 25 trips followed by Oak samples with and without coating approximately 0.01 mm, 0.02 mm and 0.028 mm after 10, 25 & 50 trips respectively. Casuarina Glauca samples had minimal indentation with averages of 0.004 mm, 0.006 mm and 0.0078 mm after 10, 25 and 50 trips respectively.

To be able to determine if there is a significant statistical difference between the indentations in the Casuarina Glauca samples and the Oak samples with different finishes, a Two-Factor ANOVA was performed for 25 trips and 50 trips shown in Table 22 and Table 23. The results of the analysis show that there is a significant difference in the means of the different types of wood but not the different finishing types nor the interactions in both the 25 trips and 50 trips analysis. A Single-Factor ANOVA was also done for the different finish types in the Casuarina

Glauca samples as shown in Table 24 and Table 25 however, we could not reject the null hypothesis therefore we cannot prove that the finish type had a significant difference on the performance of this test.

Therefore, it is safe to say that the Casuarina Glauca samples had higher resistance to rolling loads followed by the Oak samples and then the Pine samples. While the finishing type did not contribute to the resistance of the rolling load of the wooden flooring system.

Figure 41 - Indentation on one of the Oak, Pine & Casuarina Glauca samples after 25 trips with points 1, 2 & 3 marked with an "X" for measurement

Figure 42 - Oak and Pine Samples after testing

Figure 43 - Casuarina Glauca Samples after testing

Table 19 - Indentation measurements at points 1, 2&3 for the Oak samples

		Initial Reading	Dial reading 10 trips	Dial reading 25 trips	Dial reading 50 trips	Indentation 10 trips	Indentation 25 trips	Indentation 50 trips
A-1	Point 1	0.000	0.000	0.016	0.043	0.000	0.016	0.043
	Point 2	0.008	0.012	0.049	0.060	0.004	0.041	0.052
	Point 3	0.010	0.016	0.065	0.070	0.006	0.055	0.060
	Avg.	0.006	0.009	0.043	0.058	0.003	0.037	0.052
A-2	Point 1	0.028	0.035	0.033	0.060	0.007	0.005	0.032
	Point 2	0.021	0.028	0.026	0.048	0.007	0.005	0.027
	Point 3	0.021	0.018	0.025	0.033	-0.003	0.004	0.012
	Avg.	0.023	0.027	0.028	0.047	0.004	0.005	0.024
A-3	Point 1	0.016	0.017	0.026	0.025	0.001	0.010	0.009
	Point 2	0.015	0.014	0.015	0.025	-0.001	0.000	0.010
	Point 3	0.012	0.019	0.015	0.019	0.007	0.003	0.007
	Avg.	0.014	0.017	0.019	0.023	0.002	0.004	0.009
A-4	Point 1	0.030	0.033	0.034	0.045	0.003	0.004	0.015
	Point 2	0.032	0.050	0.051	0.041	0.018	0.019	0.009
	Point 3	0.050	0.062	0.133	0.141	0.012	0.083	0.091
	Avg.	0.037	0.048	0.073	0.076	0.011	0.035	0.038
A-5	Point 1	0.024	0.033	0.040	0.046	0.009	0.016	0.022
	Point 2	0.033	0.038	0.040	0.044	0.005	0.007	0.011
	Point 3	0.031	0.032	0.038	0.048	0.001	0.007	0.017
	Avg.	0.029	0.034	0.039	0.046	0.005	0.010	0.017
A-6	Point 1	0.027	0.058	0.069	0.065	0.031	0.042	0.038
	Point 2	0.030	0.064	0.067	0.064	0.034	0.037	0.034
	Point 3	0.046	0.055	0.052	0.059	0.009	0.006	0.013
	Avg.	0.034	0.059	0.063	0.063	0.025	0.028	0.028
A-7	Point 1	0.037	0.029	0.053	0.054	-0.008	0.016	0.017
	Point 2	0.027	0.028	0.038	0.048	0.001	0.011	0.021
	Point 3	0.027	0.040	0.041	0.043	0.013	0.014	0.016
	Avg.	0.030	0.032	0.044	0.048	0.002	0.014	0.018
A-8	Point 1	0.035	0.053	0.091	0.098	0.018	0.056	0.063
	Point 2	0.030	0.030	0.058	0.048	0.000	0.028	0.018
	Point 3	0.018	0.038	0.055	0.051	0.020	0.037	0.033
	Avg.	0.028	0.040	0.068	0.066	0.013	0.040	0.038

Table 20 - Indentation measurements at points 1, 2&3 for the Pine samples

		Initial Reading	Dial reading 10 trips	Dial reading 25 trips	Indentation 10 trips	Indentation 25 trips
B-1	Point 1	0.060	0.409	0.469	0.349	0.409
	Point 2	0.053	0.300	0.365	0.247	0.312
	Point 3	0.043	0.385	0.470	0.342	0.427
	Avg.	0.052	0.365	0.435	0.313	0.383
B-2	Point 1	0.025	0.215	0.324	0.190	0.299
	Point 2	0.028	0.205	0.328	0.177	0.300
	Point 3	0.028	0.260	0.330	0.232	0.302
	Avg.	0.027	0.227	0.327	0.200	0.300
B-3	Point 1	0.029	0.090	0.218	0.061	0.189
	Point 2	0.016	0.067	0.206	0.051	0.190
	Point 3	0.037	0.146	0.294	0.109	0.257
	Avg.	0.027	0.101	0.239	0.074	0.212
B-4	Point 1	0.025	0.442	0.500	0.417	0.475
	Point 2	0.023	0.487	0.552	0.464	0.529
	Point 3	0.020	0.602	0.631	0.582	0.611
	Avg.	0.023	0.510	0.561	0.488	0.538
B-5	Point 1	0.037	0.073	0.080	0.036	0.043
	Point 2	0.017	0.148	0.257	0.131	0.240
	Point 3	0.012	0.177	0.257	0.165	0.245
	Avg.	0.022	0.133	0.198	0.111	0.176
B-6	Point 1	0.030	0.430	0.580	0.400	0.550
	Point 2	0.037	0.416	0.585	0.379	0.548
	Point 3	0.036	0.440	0.582	0.404	0.546
	Avg.	0.034	0.429	0.582	0.394	0.548
B-7	Point 1	0.029	0.258	0.380	0.229	0.351
	Point 2	0.040	0.256	0.364	0.216	0.324
	Point 3	0.039	0.192	0.314	0.153	0.275
	Avg.	0.036	0.235	0.353	0.199	0.317
B-8	Point 1	0.057	0.324	0.423	0.267	0.366
	Point 2	0.042	0.396	0.498	0.354	0.456
	Point 3	0.058	0.382	0.462	0.324	0.404
	Avg.	0.052	0.367	0.461	0.315	0.409

Table 21 - Indentation measurements at points 1, 2&3 for the Casuarina Glauca samples

		Initial Reading	Dial reading 10 trips	Dial reading 25 trips	Dial reading 50 trips	Indentation 10 trips	Indentation 25 trips	Indentation 50 trips
C-1	Point 1	0.022	0.013	0.022	0.021	-0.009	0.000	-0.001
	Point 2	0.010	0.009	0.004	0.004	-0.001	-0.006	-0.006
	Point 3	0.022	0.017	0.012	0.015	-0.005	-0.010	-0.007
	Avg.	0.018	0.013	0.013	0.013	-0.005	-0.005	-0.005
C-2	Point 1	0.016	0.005	0.014	0.024	-0.011	-0.002	0.008
	Point 2	0.032	0.008	0.016	0.017	-0.024	-0.016	-0.015
	Point 3	0.055	0.041	0.042	0.042	-0.014	-0.013	-0.013
	Avg.	0.034	0.018	0.024	0.028	-0.016	-0.010	-0.007
C-3	Point 1	0.035	0.000	0.034	0.021	-0.035	-0.001	-0.014
	Point 2	0.006	0.004	0.003	0.004	-0.002	-0.003	-0.002
	Point 3	0.064	0.034	0.026	0.008	-0.030	-0.038	-0.056
	Avg.	0.035	0.013	0.021	0.011	-0.022	-0.014	-0.024
C-4	Point 1	0.024	0.024	0.035	0.023	0.000	0.011	-0.001
	Point 2	0.048	0.022	0.007	0.018	-0.026	-0.041	-0.030
	Point 3	0.003	0.001	0.007	0.009	-0.002	0.004	0.006
	Avg.	0.025	0.016	0.016	0.017	-0.009	-0.009	-0.008
C-5	Point 1	0.006	0.009	0.009	0.015	0.003	0.003	0.009
	Point 2	0.003	0.006	0.009	0.013	0.003	0.006	0.010
	Point 3	0.000	0.000	0.000	0.006	0.000	0.000	0.006
	Avg.	0.003	0.005	0.006	0.011	0.002	0.003	0.008
C-6	Point 1	0.005	0.010	0.010	0.014	0.005	0.005	0.009
	Point 2	0.003	0.004	0.005	0.008	0.001	0.002	0.005
	Point 3	0.008	0.007	0.009	0.013	-0.001	0.001	0.005
	Avg.	0.005	0.007	0.008	0.012	0.002	0.003	0.006
C-7	Point 1	0.000	0.002	0.005	0.008	0.002	0.005	0.008
	Point 2	0.004	0.005	0.008	0.008	0.001	0.004	0.004
	Point 3	0.002	0.019	0.027	0.033	0.017	0.025	0.031
	Avg.	0.002	0.009	0.013	0.016	0.007	0.011	0.014
C-8	Point 1	0.000	0.002	0.009	0.008	0.002	0.009	0.008
	Point 2	0.003	0.003	0.006	0.009	0.000	0.003	0.006
	Point 3	0.002	0.003	0.007	0.011	0.001	0.005	0.009
	Avg.	0.002	0.003	0.007	0.009	0.001	0.006	0.008
C-9	Point 1	0.016	0.004	0.011	0.008	-0.012	-0.005	-0.008
	Point 2	0.019	0.008	0.006	0.010	-0.011	-0.013	-0.009
	Point 3	0.022	0.004	0.009	0.005	-0.018	-0.013	-0.017
	Avg.	0.019	0.005	0.009	0.008	-0.014	-0.010	-0.011
C-10	Point 1	0.023	0.006	0.006	0.006	-0.017	-0.017	-0.017
	Point 2	0.003	0.001	0.011	0.011	-0.002	0.008	0.008
	Point 3	0.008	0.001	0.006	0.001	-0.007	-0.002	-0.007
	Avg.	0.011	0.003	0.008	0.006	-0.009	-0.004	-0.005
C-11	Point 1	0.029	0.043	0.020	0.024	0.014	-0.009	-0.005
	Point 2	0.005	0.002	0.003	0.016	-0.003	-0.002	0.011
	Point 3	0.075	0.080	0.050	0.047	0.005	-0.025	-0.028
	Avg.	0.036	0.042	0.024	0.029	0.005	-0.012	-0.007
C-12	Point 1	0.026	0.005	0.018	0.019	-0.021	-0.008	-0.007
	Point 2	0.006	0.002	0.013	0.018	-0.004	0.007	0.012
	Point 3	0.002	0.004	0.010	0.011	0.002	0.008	0.009
	Avg.	0.011	0.004	0.014	0.016	-0.008	0.002	0.005

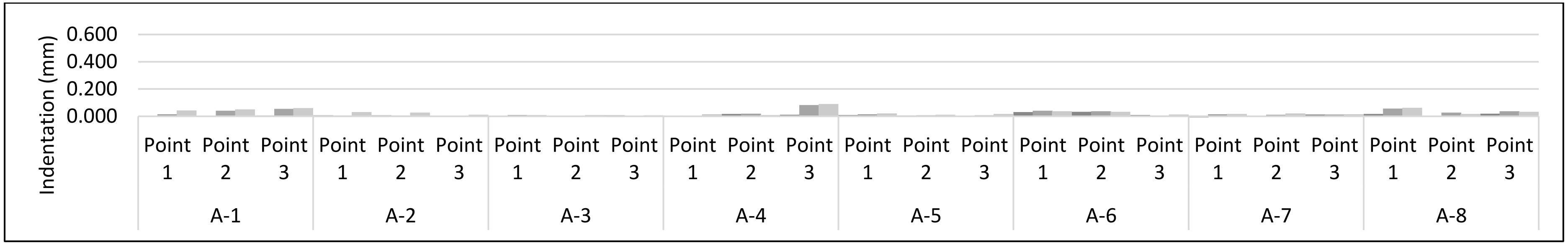


Figure 44 - Indentation measurements of Oak samples after 10, 25&50 trips

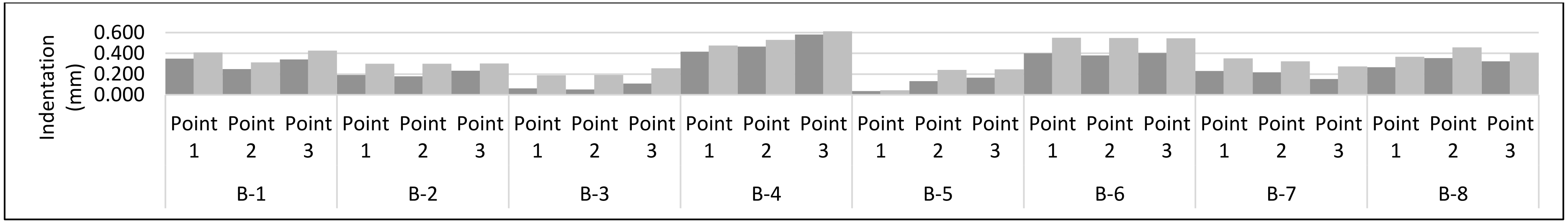


Figure 45 - Indentation measurements of Pine samples after 10&25 trips

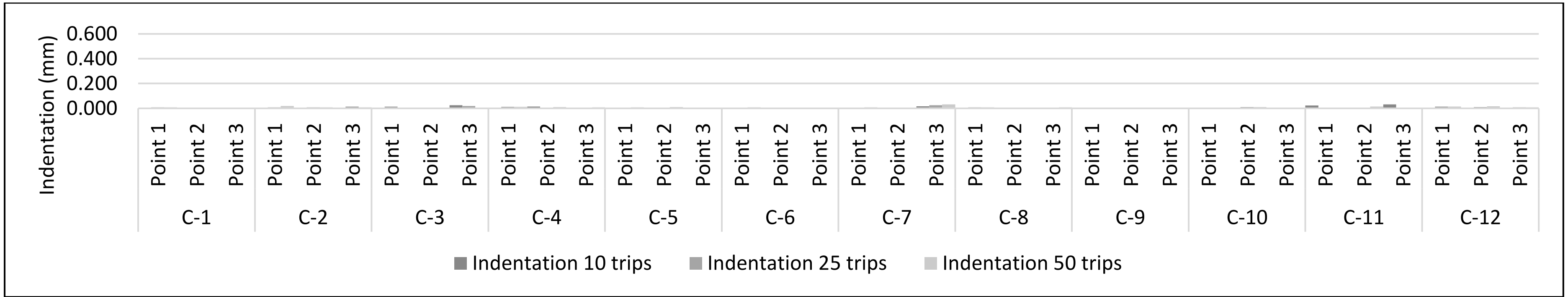


Figure 46 - Indentation measurements of Casuarina Glauca samples after 10, 25&50 trips

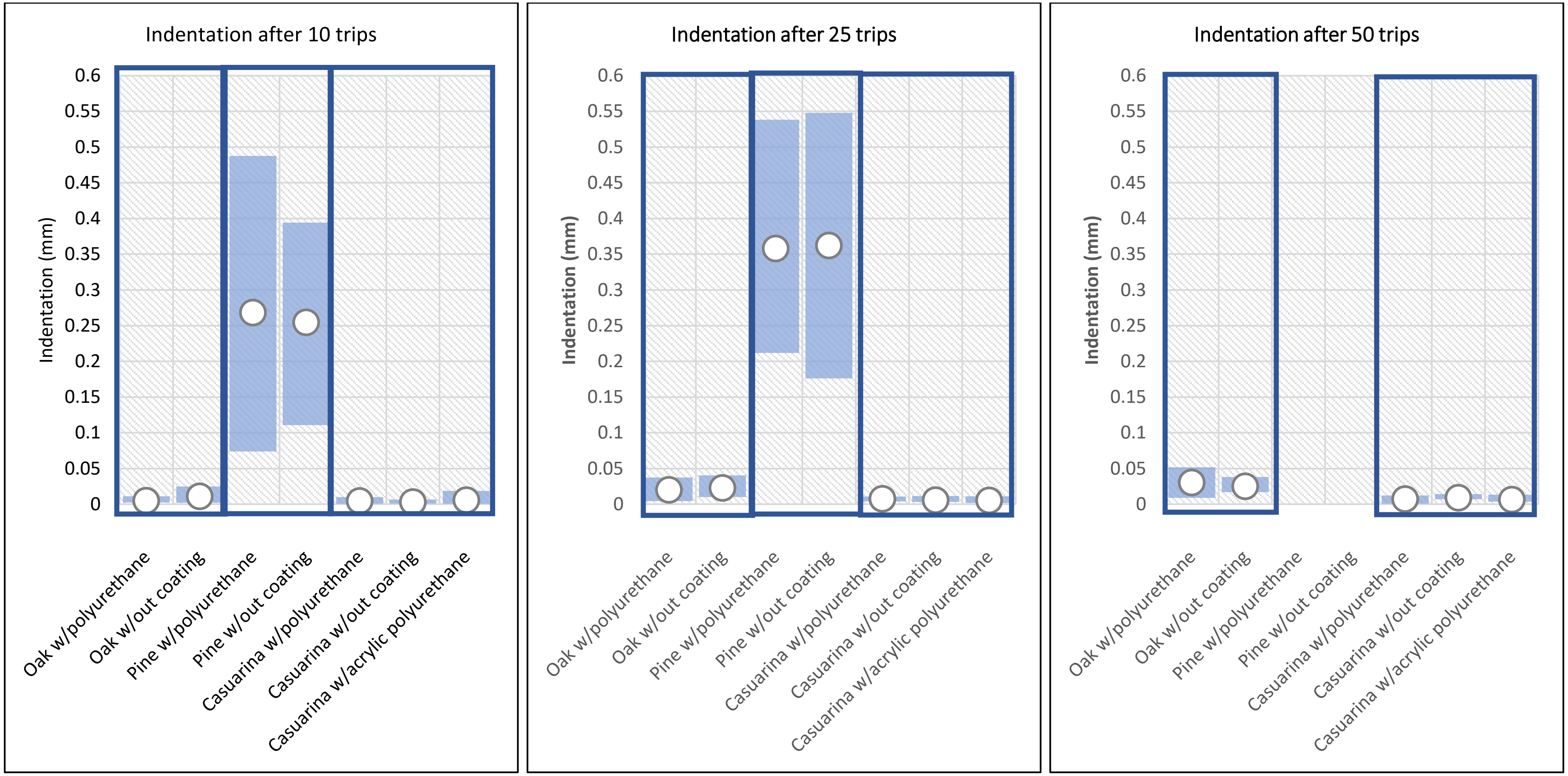


Figure 47 - Comparison of indentations in Oak, Pine & Casuarina Glauca samples after 10, 25 & 50 trips

Table 22 - Two Factor ANOVA for 25 trips

Anova: Two-Factor With Replication (25 trips)

SUMMARY	Finish 1	Unfinished	Total
Casuarina			
Count	4	4	8
Sum	0.031	0.023667	0.054667
Average	0.00775	0.005917	0.006833
Variance	1.08E-05	1.48E-05	1.19E-05
Oak			
Count	4	4	8
Sum	0.081667	0.092333	0.174
Average	0.020417	0.023083	0.02175
Variance	0.000338	0.000195	0.000231
Total			
Count	8	8	
Sum	0.112667	0.116	
Average	0.014083	0.0145	
Variance	0.000196	0.000174	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Type of Wood	0.00089	1	0.00089	6.36787	0.026739	4.747225
Type of Finish	6.94E-07	1	6.94E-07	0.004969	0.944966	4.747225
Interaction	2.03E-05	1	2.03E-05	0.144882	0.710127	4.747225
Within	0.001677	12	0.00014			
Total	0.002588	15				

Table 23 - One Factor ANOVA for different finishes in Casuarina, 25 trips

Anova: Single Factor (25 trips)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Finish 1	4	0.031	0.00775	1.08E-05
Unfinished	4	0.023667	0.005917	1.48E-05
Finish 2	4	0.022333	0.005583	1.53E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.09E-05	2	5.44E-06	0.399366	0.682067	4.256495
Within Groups	0.000123	9	1.36E-05			
Total	0.000134	11				

Table 24 - Two Factor ANOVA for 50 trips

Anova: Two-Factor With Replication (50 trips)

SUMMARY	Finish 1	Unfinished	Total
Casuarina			
Count	4	4	8
Sum	0.029	0.037333	0.066333
Average	0.00725	0.009333	0.008292
Variance	2.71E-05	1.14E-05	1.77E-05
Oak			
Count	4	4	8
Sum	0.122333	0.101	0.223333
Average	0.030583	0.02525	0.027917
Variance	0.000344	9.94E-05	0.000198
Total			
Count	8	8	
Sum	0.151333	0.138333	
Average	0.018917	0.017292	
Variance	0.000315	0.00012	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Type of Wood	0.001541	1	0.001541	12.78058	0.003817	4.747225
Type of Finish	1.06E-05	1	1.06E-05	0.087627	0.772276	4.747225
Interaction	5.5E-05	1	5.5E-05	0.45634	0.512147	4.747225
Within	0.001446	12	0.000121			
Total	0.003053	15				

Table 25 - One Factor ANOVA for different finishes in Casuarina, 50 trips

Anova: Single Factor (50 trips)

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Finish 1	4	0.029	0.00725	2.71E-05
Unfinished	4	0.037333	0.009333	1.14E-05
Finish 2	4	0.026333	0.006583	2.17E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.65E-05	2	8.23E-06	0.410687	0.675019	4.256495
Within Groups	0.00018	9	2E-05			
Total	0.000197	11				

5.1.5 Floor surface indentation from small area loads

As indicated in the ASTM D2394-17, the floor surface indentation from small area loads test is a qualitative test and the damage to the surface shall be described as none to minor, moderate, severe and complete damage. As shown in Figure 48 & Figure 49 below, the damage resulted from the roller being moved 100 trips back and forth was severe in the Pine samples due to their low density while the Oak and Casuarina Glauca samples were less affected showing moderate damage. It can be deduced that the damage due to the small area loads is directly proportional to the density of wood.

Figure 48 - Casuarina Glauca Samples laid perpendicular to the roller after 100 trips

Figure 49 - Oak, Pine & Casuarina Glauca Samples laid parallel to the roller after 100 trips

5.1.6 Surface wetting

After leaving the samples for 48 hours in contact with a moist surface, the doming was measured using a Vernier calliper at both ends and at the center of the sample as shown in Figure 50. The average doming was estimated to be an average of the difference between each edge and the center of the sample. Figure 51 - Figure 56 show the samples after tesing.

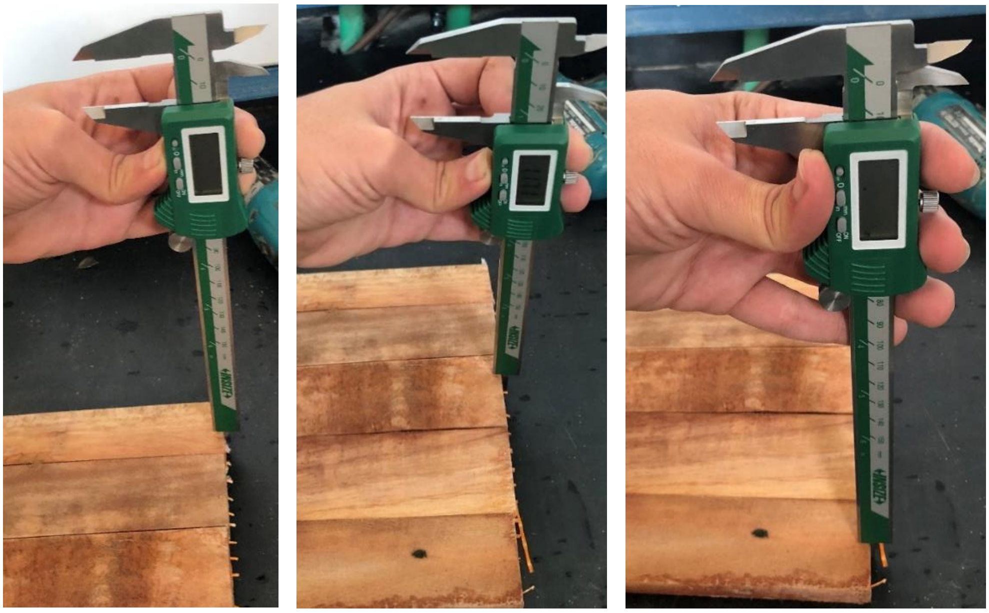


Figure 50 - Vernier Calliper used to measure thickness of the samples at both edges and center in order to determine amount of doming

Figure 57 shows the plotted profiles of the restrained and unrestrained samples using the 3 points described earlier. The difference in means and variances of the tested samples are shown in Figure 58 and it can be deduced graphically that the unrestrained samples had less doming when compared to the restrained samples. However, it is difficult to determine from the graph if a certain wood type or finish had better performance in terms of doming. Therefore, statistical analysis was performed. A Two Factor ANOVA was performed on the Oak, Pine & Casuarina Glauca samples with different finishes for the restrained test shown in Table 26 The results showed that there is statistical evidence to reject the null hypotheses related to the different types of wood and different types of finish but no statistical evidence to prove significant difference in the interactions. A similar test was performed for the unrestrained test however, the results indicated no significant differences between the different types of wood nor finishing. The Pine samples were then removed from the sample and another Two Factor ANOVA was performed between the Oak and Casuarina only shown in Table 27 Results showed that there are significant differences between the types of finish only where the finished samples had significantly lower doming when compared to the samples without coating. Furthermore, a Single Factor ANOVA was then performed for the Casuarina samples with the different types of finishes shown in Table 28 and the results indicate that there are significant differences between the means of the different finishes, 0.06, 0.16, and 0.60 mm for the acrylic polyurethane, polyurethane and the no finish samples respectively. Hence it could be concluded that the type of finish has an impact on the performance of wooden flooring systems in terms of distortion due to surface wetting. It is also proved that the performance of acrylic polyurethane in terms of surface wetting is better than polyurethane.

Figure 51 - Oak, Pine & Casuarina Glauca samples after unrestrained surface wetting test

Figure 52 - Oak sample finished with polyurethane after restrained surface wetting

Figure 53 - Pine sample finished with polyurethane after restrained surface wetting

Figure 54 - Casuarina Glauca samples finished with polyurethane after restrained surface wetting

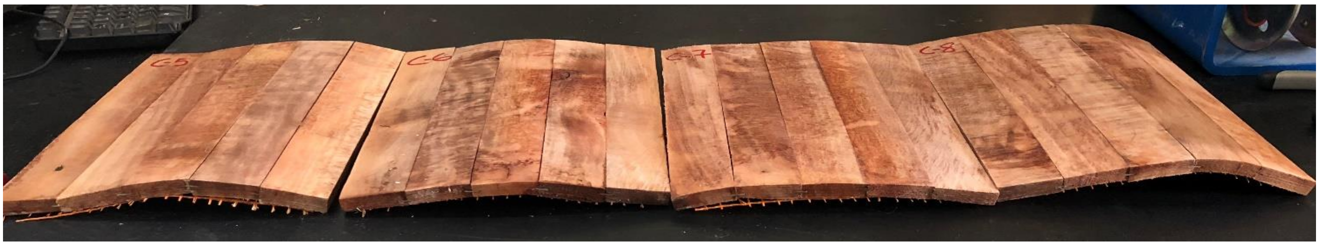


Figure 55 - Casuarina Glauca samples without finish after restrained surface wetting

Figure 56 - Casuarina Glauca samples finished with acrylic polyurethane after restrained surface wetting

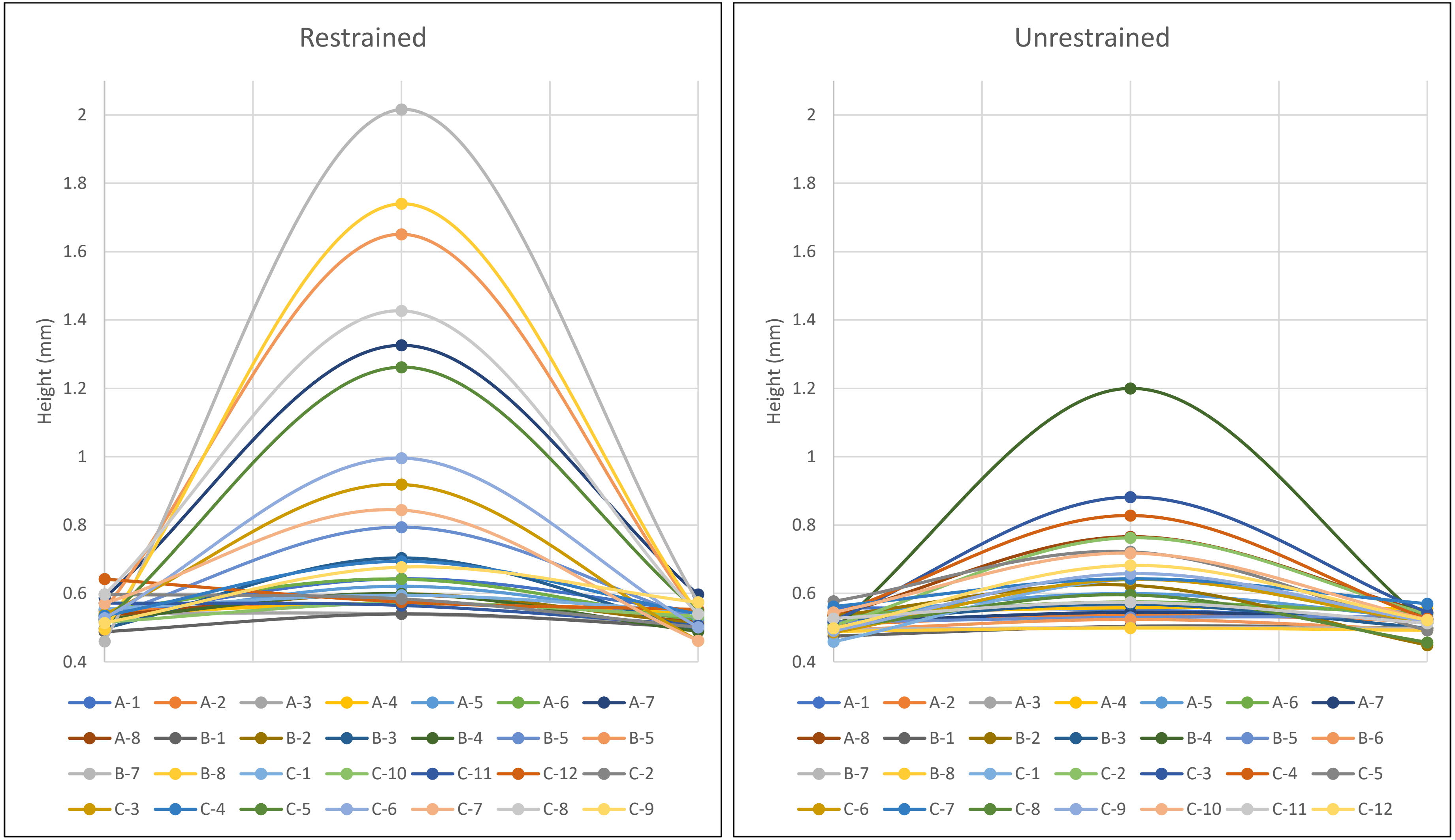


Figure 57 - Profile of the Oak, Pine & Casuarina Glauca samples after the restrained & unrestrained surface wetting test

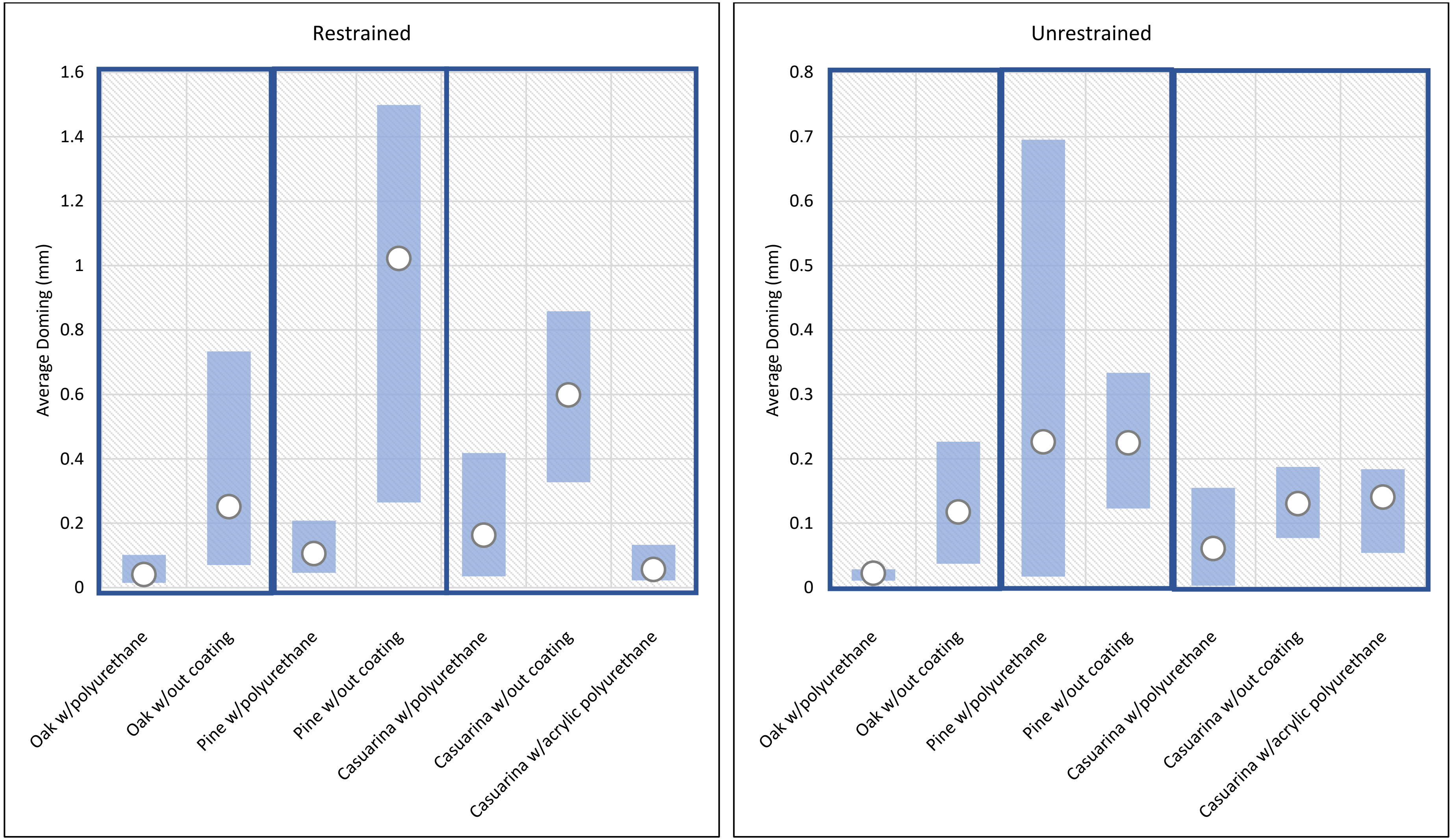


Figure 58 - Comparison between the doming of the Oak, Pine & Casuarina Glauca samples after the restrained & unrestrained surface wetting test

Table 26 - Two Factor ANOVA for Oak, Pine & Casuarina samples with different finishes

Anova: Two-Factor With Replication (Restrained)

SUMMARY	Finish 1	Unfinished	Total
Casuarina			
Count	4	4	8
Sum	0.6535	2.3955	3.049
Average	0.163375	0.598875	0.381125
Variance	0.031995	0.057167	0.092401
Oak			
Count	4	4	8
Sum	0.167	1.0075	1.1745
Average	0.04175	0.251875	0.146813
Variance	0.001649	0.103324	0.057603
Pine			
Count	4	4	8
Sum	0.426	4.091	4.517
Average	0.1065	1.02275	0.564625
Variance	0.004958	0.282449	0.363036
Total			
Count	12	12	
Sum	1.2465	7.494	
Average	0.103875	0.6245	
Variance	0.013221	0.229205	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Type of Wood	0.701712	2	0.350856	4.371651	0.028348	3.554557
Type of Finish	1.626302	1	1.626302	20.26367	0.000276	4.413873
Interaction	0.520351	2	0.260176	3.241779	0.062745	3.554557
Within	1.444627	18	0.080257			
Total	4.292992	23				

Table 27 - Two Factor ANOVA for Oak & Casuarina samples with different finishes

Anova: Two-Factor With Replication

SUMMARY	Finish 1	Unfinished	Total
Casuarina			
Count	4	4	8
Sum	0.6535	2.3955	3.049
Average	0.163375	0.598875	0.381125
Variance	0.031995	0.057167	0.092401
Oak			
Count	4	4	8
Sum	0.167	1.0075	1.1745
Average	0.04175	0.251875	0.146813
Variance	0.001649	0.103324	0.057603
Total			
Count	8	8	
Sum	0.8205	3.403	
Average	0.102563	0.425375	
Variance	0.018646	0.103184	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Type of Wood	0.219609	1	0.219609	4.524889	0.05483	4.747225
Type of Finish	0.416832	1	0.416832	8.588508	0.01259	4.747225
Interaction	0.050794	1	0.050794	1.046571	0.32648	4.747225
Within	0.582404	12	0.048534			
Total	1.269639	15				

Table 28 - Single Factor ANOVA for type of finish in Casuarina samples

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Finish 1	4	0.6535	0.163375	0.031995
Unfinished	4	2.3955	0.598875	0.057167
Finish 2	4	0.2285	0.057125	0.002683

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.659257	2	0.329628	10.7669	0.004098	4.256495
Within Groups	0.275535	9	0.030615			
Total	0.934791	11				

5.1.7 Coefficient of friction

The value of the coefficient of static friction is determined by dividing the force required to move the stationary sliding weight by the weight of the sliding unit. The values of the calculated coefficient of static friction are tabulated below in Table 29.

The graphical test results of the coefficient of friction test did not reveal significant differences between the types of wood and the different finishes. Therefore, a Two Factor ANOVA was performed (Table 30) and the results showed that there is enough statistical evidence to reject the null hypothesis regarding the type of wood, type of finish and interaction in between. The Casuarina Glauca had the highest mean of coefficient of friction 0.59 followed by the Pine 0.53 and finally is the Oak 0.49. A Single Factor ANOVA was performed later between the different types of finish in the Casuarina samples and the results indicated statistical difference between the different types of finish with polyurethane having the highest coefficient of friction followed by the uncoated samples and then the polyurethane samples. The value of the coefficient of static friction is determined by dividing the force required to move the stationary sliding weight by the weight of the sliding unit. The values of the calculated coefficient of static friction are tabulated below.

Therefore, it is concluded that the type of wood as well as the type of coating used as finishing have a major impact on the slipperiness of the wooden flooring and this is confirmed by the test results where the least values for coefficient of friction correspond to the finished samples.

Table 29 - Force required to move sliding weight and Coefficient of static friction for Oak, Pine & Casuarina Glauca samples

	Scale Reading (kg)	Coefficient of Static Friction
A-1	5.13	0.4461
A-2	5.3	0.4609
A-3	4.8	0.4174
A-4	5.4	0.4696
A-5	6.1	0.5304
A-6	5.9	0.5130
A-7	6.2	0.5391
A-8	6.5	0.5652
B-1	5.8	0.5043
B-2	6.3	0.5478
B-3	6	0.5217
B-4	5.9	0.5130
B-5	6.25	0.5435
B-6	6.1	0.5304
B-7	6.4	0.5565
B-8	6.8	0.5913
C-1	7.3	0.6348
C-2	6.8	0.5913
C-3	6.9	0.6000
C-4	6.8	0.5913
C-5	6.5	0.5652
C-6	6.6	0.5739
C-7	6.9	0.6000
C-8	6.5	0.5652
C-9	5.7	0.4957
C-10	5.8	0.5043
C-11	5.7	0.4957
C-12	5.8	0.5043

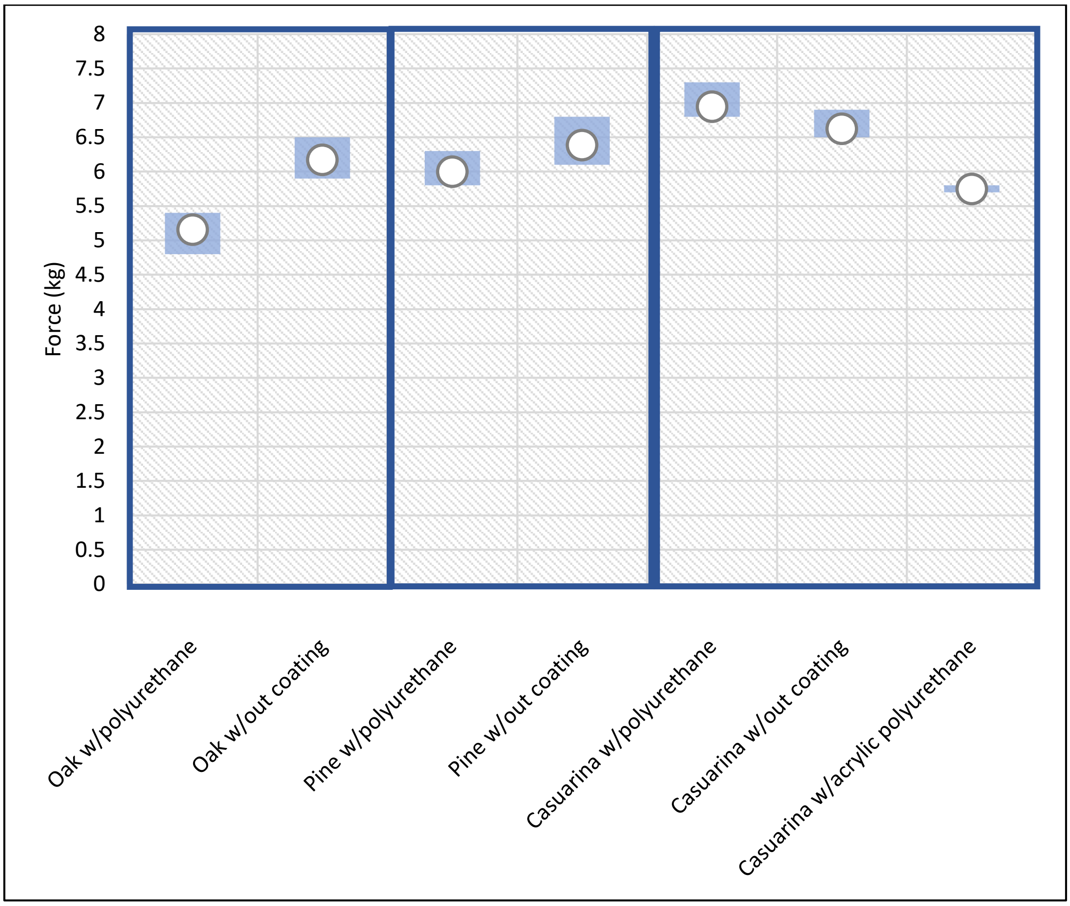


Figure 59 - Average force required to move sliding weight

Table 30 - Two Factor ANOVA for the type of wood and finish of all samples

Anova: Two-Factor With Replication

SUMMARY	Finish 1	Unfinished	Total
Casuarina			
Count	4	4	8
Sum	2.417391	2.304348	4.721739
Average	0.604348	0.576087	0.590217
Variance	0.000428	0.000271	0.000528
Oak			
Count	4	4	8
Sum	1.793913	2.147826	3.941739
Average	0.448478	0.536957	0.492717
Variance	0.000523	0.000473	0.002664
Pine			
Count	4	4	8
Sum	2.086957	2.221739	4.308696
Average	0.521739	0.555435	0.538587
Variance	0.000353	0.000685	0.000769
Total			
Count	12	12	
Sum	6.298261	6.673913	
Average	0.524855	0.556159	
Variance	0.004778	0.000668	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Wood	0.038069	2	0.019035	41.77947	1.73E-07	3.554557
Finish	0.00588	1	0.00588	12.90563	0.002082	4.413873
Interaction	0.013645	2	0.006823	14.97504	0.000148	3.554557
Within	0.008201	18	0.000456			
Total	0.065795	23				

5.1.8 Abrasion Resistance

Figure 60 - Some of the samples after abrasion test showing apparent loss in thickness for subsequent weight measurement

Figure 60 shows the samples tested in the abrasion resistance test which were weighed before and after the test in order to determine the weight lost due to abrasion. Table 31 below shows the initial, final and abraded weights of the samples. It was observed graphically that the Pine samples had the highest percentages of weight loss due to abrasion including all types of coatings in comparison with Oak samples and Casuarina Glauca. A statistical analysis was also performed to check if the differences in the means were significant or not. A Two Factor ANOVA was initially performed for all types of wood (Table 32) and the results showed that there is significant difference in the means due to the type of wood and type of finish since the statistical F-values were higher than the critical F-values. The Casuarina had the lowest average of 7% followed by the Oak 11% while the Pine had the highest average percentage of mass loss of 16%. A Single Factor ANOVA was then performed between the different types of finish in the Casuarina samples (Table 33) and the results showed that there was significant difference due to the type of finish.

Therefore, it can be concluded that there is a significant difference between the different types of wood in terms of abrasion resistance; Casuarina has the highest abrasion resistance followed by Oak and then Pine. Also, it is also proved that the type of finish has an impact on the abrasion resistance of the wooden flooring where the samples coated with polyurethane or acrylic polyurethane showed smaller percentages of mass loss due to abrasion.

Table 31 - Initial, final and abraded weight of Oak, Pine & Casuarina Glauca samples with different types of coating

Sample	Initial Weight (g)	Final Weight (g)	Abraded Weight (g)	% Loss in Weight
Pine w/acrylic polyurethane-3	12	7.75	4.25	35.4%
Pine w/ polyurethane-3	11.8	8.32	3.48	29.5%
Pine w/out coating-7	11.7	8.33	3.37	28.8%
Pine w/ polyurethane-1	12	8.76	3.24	27.0%
Pine w/ polyurethane-5	12.4	9.06	3.34	26.9%
Pine w/out coating-1	11.1	8.16	2.94	26.5%
Pine w/ polyurethane-7	11.9	8.92	2.98	25.0%
Pine w/acrylic polyurethane-9	12.5	9.55	2.95	23.6%
Pine w/ polyurethane-16	13.9	10.63	3.27	23.5%
Pine w/out coating-14	12.7	10.01	2.69	21.2%
Pine w/ polyurethane-11	11.7	9.23	2.47	21.1%
Pine w/acrylic polyurethane-17	11.6	9.17	2.43	20.9%
Pine w/ polyurethane-17	11.3	8.98	2.32	20.5%
Pine w/out coating-3	11.9	9.46	2.44	20.5%
Pine w/ polyurethane-8	11.4	9.08	2.32	20.4%
Pine w/ polyurethane-9	11.5	9.16	2.34	20.3%
Pine w/out coating-15	12.3	9.92	2.38	19.3%
Oak w/out coating-14	20	16.16	3.84	19.2%
Pine w/out coating-9	10.2	8.25	1.95	19.1%
Pine w/ polyurethane-20	11.7	9.47	2.23	19.1%
Pine w/acrylic polyurethane-5	11.9	9.64	2.26	19.0%
Pine w/out coating-19	11.8	9.59	2.21	18.7%
Pine w/out coating-21	11.5	9.37	2.13	18.5%
Pine w/ polyurethane-12	11.8	9.62	2.18	18.5%
Pine w/ polyurethane-18	12.4	10.12	2.28	18.4%
Pine w/ polyurethane-2	11.6	9.47	2.13	18.4%
Pine w/out coating-12	14	11.52	2.48	17.7%
Pine w/ polyurethane-10	12.1	9.96	2.14	17.7%
Pine w/out coating-8	11.2	9.22	1.98	17.7%
Oak w/out coating-12	20.6	16.99	3.61	17.5%
Pine w/acrylic polyurethane-18	12.1	10.1	2	16.5%
Oak w/ polyurethane-12	19.5	16.37	3.13	16.1%
Pine w/ polyurethane-4	12.8	10.76	2.04	15.9%
Oak w/ polyurethane-3	20	16.84	3.16	15.8%
Pine w/out coating-13	11.4	9.61	1.79	15.7%
Oak w/acrylic polyurethane-4	21.3	18.01	3.29	15.4%
Pine w/out coating-4	11.4	9.65	1.75	15.4%
Oak w/acrylic polyurethane-2	20.2	17.1	3.1	15.3%
Oak w/acrylic polyurethane-14	22.4	18.99	3.41	15.2%
Oak w/acrylic polyurethane-10	23.8	20.6	3.2	13.4%
Pine w/acrylic polyurethane-4	12.8	11.12	1.68	13.1%
Oak w/acrylic polyurethane-6	23.9	21.12	2.78	11.6%
Pine w/acrylic polyurethane-14	13	11.54	1.46	11.2%
Pine w/acrylic polyurethane-13	13.9	12.35	1.55	11.2%
Casuarina w/ polyurethane-2	20.6	18.33	2.27	11.0%
Oak w/ polyurethane-1	22	19.62	2.38	10.8%
Oak w/ polyurethane-4	21.1	18.83	2.27	10.8%
Casuarina w/ polyurethane-3	21.3	19.07	2.23	10.5%
Pine w/acrylic polyurethane-16	11.7	10.49	1.21	10.3%
Oak w/out coating-15	20.7	18.56	2.14	10.3%
Pine w/out coating-5	15.3	13.72	1.58	10.3%
Oak w/acrylic polyurethane-8	22.3	20.04	2.26	10.1%
Casuarina w/ polyurethane-8	27.1	24.41	2.69	9.9%
Oak w/ polyurethane-11	24	21.66	2.34	9.8%

Oak w/out coating-1	20	18.06	1.94	9.7%
Pine w/ polyurethane-19	14	12.65	1.35	9.6%
Casuarina w/acrylic polyurethane-10	24.9	22.59	2.31	9.3%
Casuarina w/ polyurethane-7	23.7	21.52	2.18	9.2%
Oak w/ polyurethane-5	21.1	19.21	1.89	9.0%
Pine w/ polyurethane-13	18.4	16.81	1.59	8.6%
Casuarina w/acrylic polyurethane-6	26.7	24.4	2.3	8.6%
Casuarina w/ polyurethane-9	27	24.69	2.31	8.6%
Casuarina w/out coating-11	21.6	19.8	1.8	8.3%
Oak w/out coating-3	20	18.39	1.61	8.1%
Casuarina w/ polyurethane-5	23.8	21.92	1.88	7.9%
Oak w/acrylic polyurethane-7	20	18.44	1.56	7.8%
Oak w/ polyurethane-6	23	21.23	1.77	7.7%
Pine w/out coating-16	14.2	13.15	1.05	7.4%
Casuarina w/out coating-7	21	19.45	1.55	7.4%
Casuarina w/acrylic polyurethane-3	28.1	26.19	1.91	6.8%
Casuarina w/out coating-10	21.8	20.33	1.47	6.7%
Casuarina w/out coating-6	23.4	21.83	1.57	6.7%
Oak w/out coating-5	21.4	20.21	1.19	5.6%
Casuarina w/out coating-5	26.5	25.13	1.37	5.2%
Casuarina w/acrylic polyurethane-12	28.1	26.67	1.43	5.1%
Oak w/acrylic polyurethane-13	23.7	22.5	1.2	5.1%
Casuarina w/acrylic polyurethane-5	26.3	25.06	1.24	4.7%
Casuarina w/acrylic polyurethane-7	30.3	28.96	1.34	4.4%
Casuarina w/acrylic polyurethane-2	31.1	29.79	1.31	4.2%
Casuarina w/out coating-2	23.8	22.97	0.83	3.5%
Oak w/acrylic polyurethane-9	23.6	22.78	0.82	3.5%
Casuarina w/out coating-8	27.3	26.87	0.43	1.6%

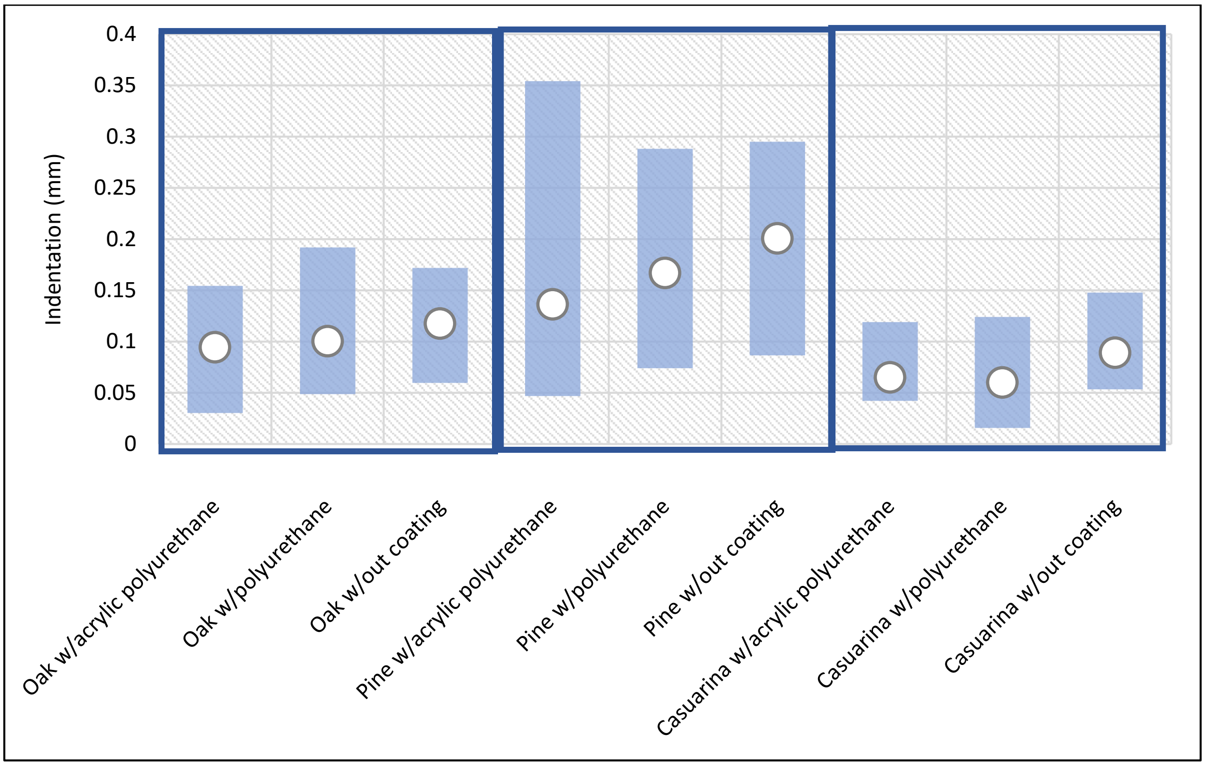


Figure 61 - Comparison between abraded weight of Oak, Pine & Casuarina Glauca samples with different types of coating

Table 32 - Two Factor ANOVA between different types of wood and different finishing

Anova: Two-Factor With Replication

SUMMARY	Finish 1	Unfinished	Finish 2	Total
Casuarina				
Count	10	10	10	30
Sum	0.60971	0.888119	0.669971	2.1678
Average	0.060971	0.088812	0.066997	0.07226
Variance	0.000952	0.00086	0.000629	0.000906
Oak				
Count	10	10	10	30
Sum	1.074672	1.206957	1.057699	3.339327
Average	0.107467	0.120696	0.10577	0.111311
Variance	0.002	0.001284	0.002012	0.001689
Pine				
Count	10	10	10	30
Sum	1.67715	1.923489	1.28371	4.88435
Average	0.167715	0.192349	0.128371	0.162812

Variance	0.002981	0.002949	0.001605	0.003056

Total			
Count	30	30	30
Sum	3.361532	4.018565	3.01138
Average	0.112051	0.133952	0.100379
Variance	0.003817	0.003519	0.001982

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Type of Wood	0.123769	2	0.061885	36.47253	5.07E-12	3.109310547
Type of Finish	0.01743	2	0.008715	5.136383	0.00794	3.109310547
Interaction	0.009023	4	0.002256	1.32943	0.266103	2.48444144
Within	0.137436	81	0.001697			
Total	0.287658	89				

Table 33 - Single Factor ANOVA for the different types of finish in the Casuarina samples

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Finish 1	10	0.60971	0.060971	0.000952
Unfinished	10	0.888119	0.088812	0.00086
Finish 2	10	0.669971	0.066997	0.000629

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.004291	2	0.002146	2.636915	0.089935	2.510609
Within Groups	0.021969	27	0.000814			
Total	0.02626	29				

5.1.9 Resistance to Staining & Cigarette Burns

The cigarette burns and resistance to staining tests involve observations to the wooden flooring surface when brought to contact with certain compounds for a set time. The Sodium Hydroxide and Hydrogen Peroxide compounds had no major effect on the surfaces of all coated samples (polyurethane and acrylic polyurethane) while a stain was found on the unfinished samples. In addition, the effect of the cigarette burns was negligible on the finished samples and left a slight mark on the uncoated samples. As for the staining agents such as Acetone, coffee and ink, there was a vivid trace of these compounds when left to dry on all the samples however, they can be easily removed with no distortion to the finished surface if they are wiped out before drying, this is only applicable to the samples with coating unlike the unfinished samples. Therefore, it can be assumed that the polyurethane coating provides sufficient protection to wooden flooring when subjected to accidental stains or cigarette burns.

Table 34 - Cigarette burns and Staining of Oak, Pine & Casuarina Glauca samples

Sample	Test Materials (Sodium Hydroxide & Hydrogen Peroxide)	Test Materials (Acetone, Ink, Coffee & cigarette burn)	Final Result
Oak w/polyurethane			
Oak w/out coating			

Pine w/polyurethane			
Pine w/out coating			
Casuarina w/polyurethane			
Casuarina w/out coating			
Casuarina w/acrylic polyurethane			

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In conclusion, the proposed Casuarina Glauca wooden flooring system was found to have improved performance characteristics when compared with the commonly used Oak and Pine wooden flooring systems. The Casuarina Glauca displayed similar or improved results when compared to the Oak samples specifically,

1. Concentrated Loading: Although the mean value for the indentation in the concentrated load test was higher for Oak (mean = 0.961 mm, variance = 0.28 mm) when compared to Casuarian Gluaca (mean = 0.815 mm, variance = 0.18 mm), the Casuarina Glauca and Oak samples showed no significant statistical difference in the concentrated loading test using ANOVA (p value = 0.5). The types of coatings compared namely, polyurethane and acrylic polyurethane were not found to contribute significantly in the concentrated loading test using single factor ANOVA (p value = 0.97)
2. Falling ball: Although the mean value for the indentation in the falling ball test was higher for Oak (mean = 449 mm, variance = 13051 mm) when compared to Casuarian Gluaca (mean = 386 mm, variance = 10870mm), the Casuarina Glauca and Oak samples showed no significant statistical difference in the falling ball test using ANOVA (p value = 0.24). The types of coatings compared namely, polyurethane and acrylic polyurethane were not found to contribute significantly in the falling ball test using single factor ANOVA (p value = 0.45)
3. Janka Hardness: The mean value for force required in the Janka hardness test was significantly higher for Oak (mean = 8.4 kN, variance = 10.2 kN) when compared to Casuarian Gluaca (mean = 11.4 kN, variance = 6.2 kN), therefore the Casuarina Glauca can be assumed to have higher hardness than the Oak samples with a statistical difference in the Janka hardness test using ANOVA (p value = 0.0001).
4. Rolling load: The mean value for the indentation in the rolling load test was significantly higher for Oak (mean = 0.028 mm, variance = 1.77E-05 mm) when compared to Casuarian Gluaca (mean = 0.008 mm, variance = 0.0002 mm), therefore the Casuarina Glauca can be assumed to have higher resistance to rolling loads than the Oak samples with a statistical difference in the rolling load test using ANOVA (p value = 0.003). The types of coatings compared namely, polyurethane and acrylic polyurethane were not found to contribute significantly in the concentrated loading test using single factor ANOVA (p value = 0.67)

5. Floor surface indentation from small area loads: the visual assessment of the damage due to small area loads was reported in the form of photographs and was found to be moderate in the Oak and Casuarina Glauca samples and severe in the Pine samples.
6. Surface Wetting: Although the doming in the surface wetting test was higher for Oak (mean = 0.15 mm, variance = 0.06 mm) when compared to Casuarian Gluaca (mean = 0.38 mm, variance = 0.09 mm), the Casuarina Glauca and Oak samples showed no significant statistical difference in the surface wetting test using ANOVA (p value = 0.055). The types of coatings compared namely, polyurethane and acrylic polyurethane were found to contribute significantly in the surface wetting test using single factor ANOVA (p value = 0.004).
7. Coefficient of friction: The mean value of the coefficient of friction test was significantly higher for Casuarian Gluaca (mean = 0.59, variance = 0.0005) followed by Pine (mean = 0.54, variance = 0.0007) and then Oak (mean = 0.49, variance = 0.02), therefore the Casuarina Glauca can be assumed to have the highest coefficient of friction with a statistical difference using ANOVA (p value = 1.73E-07). The types of coatings compared namely, polyurethane and acrylic polyurethane were found to contribute significantly in the surface wetting test using single factor ANOVA (p value = 0.002).
8. Abrasion resistance: The mean value of the percentage weight lost in the abrasion resistance test was significantly lower in Casuarian Gluaca (mean = 0.07, variance = 0.0009) followed by Oak (mean = 0.11, variance = 0.0016) and then Pine (mean = 0.16, variance = 0.003), therefore the Casuarina Glauca can be assumed to have the highest abrasion resistance with a statistical difference using ANOVA (p value = 5.07E-12). The types of coatings compared namely, polyurethane and acrylic polyurethane were found to contribute significantly in the surface wetting test using single factor ANOVA (p value = 0.007).
9. Resistance to Staining & Cigarette burns: the visual assessment of the staining and cigarette burns test showed no apparent difference between the Oak, Pine & Casuarina Glauca samples however, the difference was rather observed between the finished and unfinished samples were the samples with polyurethane and acrylic polyurethane showed higher resistance to stains and cigarette burns when compared to the samples without finishing.

6.2 Recommendations

Future recommendations for research around this topic may include:

- Using the Casuarina Glauca wood in a different flooring system design
- Using other types of coating to the wood flooring system such as epoxy resins
- Use of Casuarina Glauca wood in engineered wood flooring systems
- Use of Casuarina Glauca wood in different applications other than flooring

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